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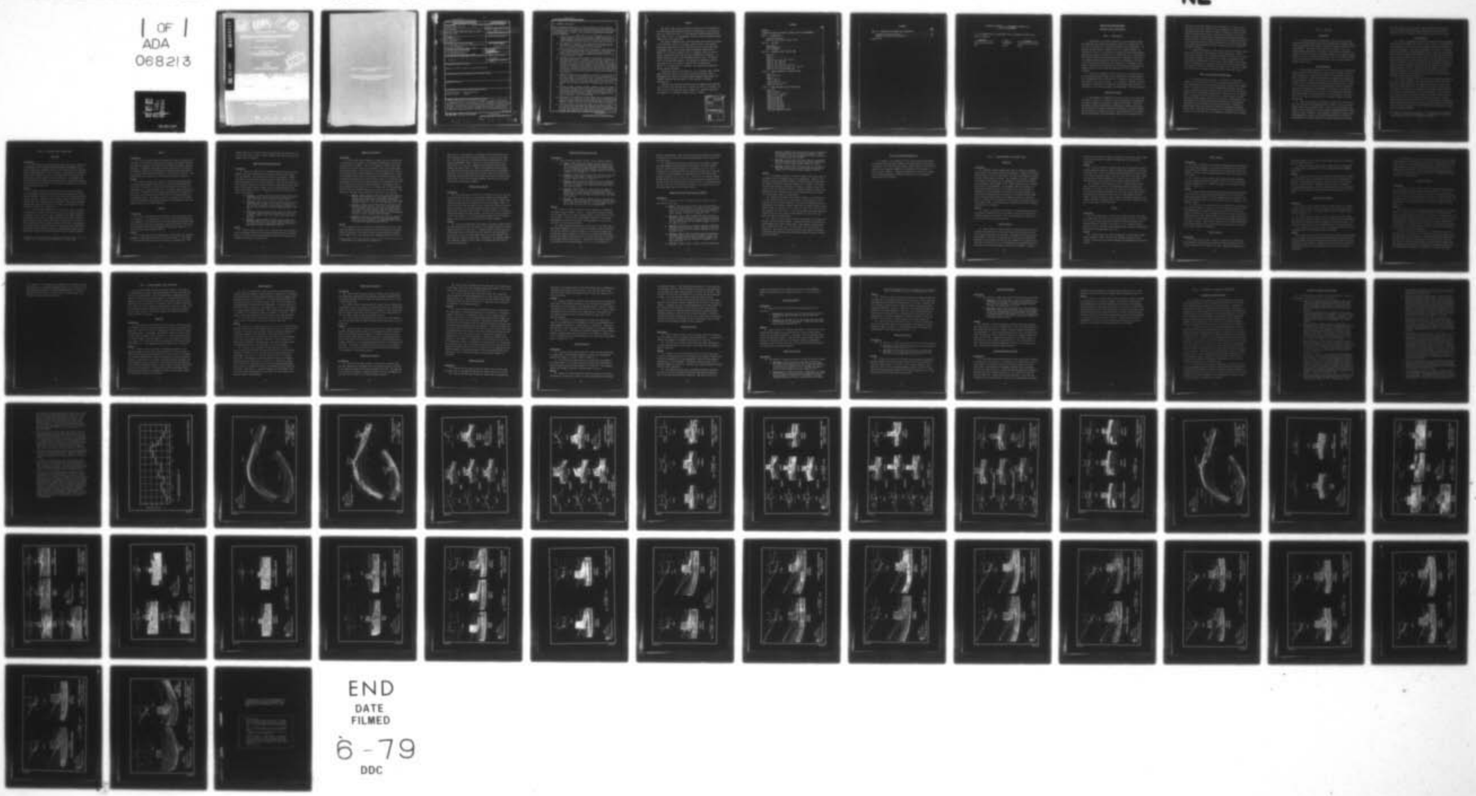

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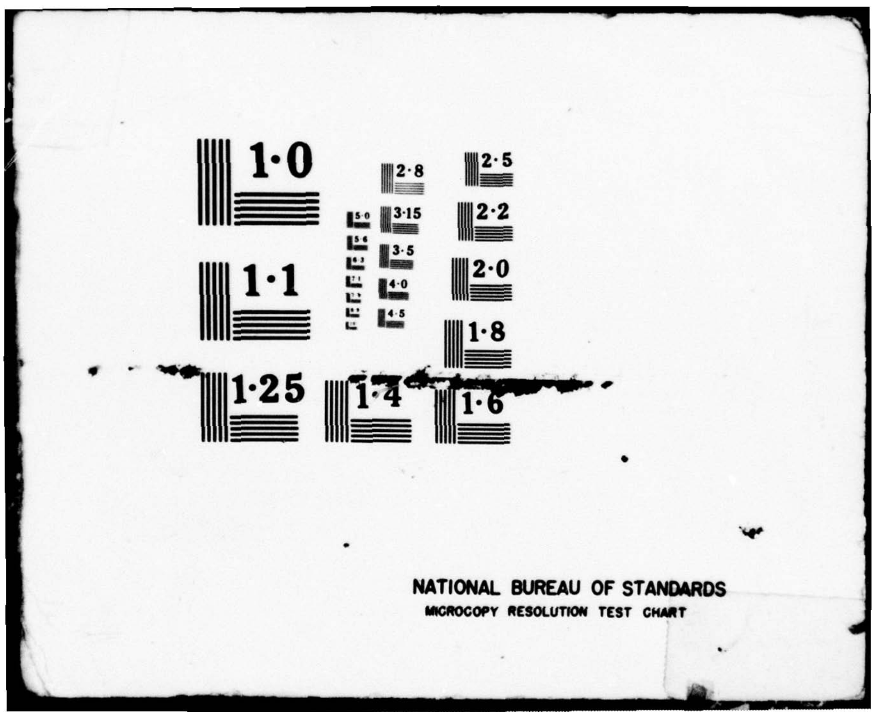
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TECHNICAL REPORT HL-79-5

SHOALING IN HARBOR ENTRANCES

Hydraulic Model Investigation

by

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March 1979

Final Report

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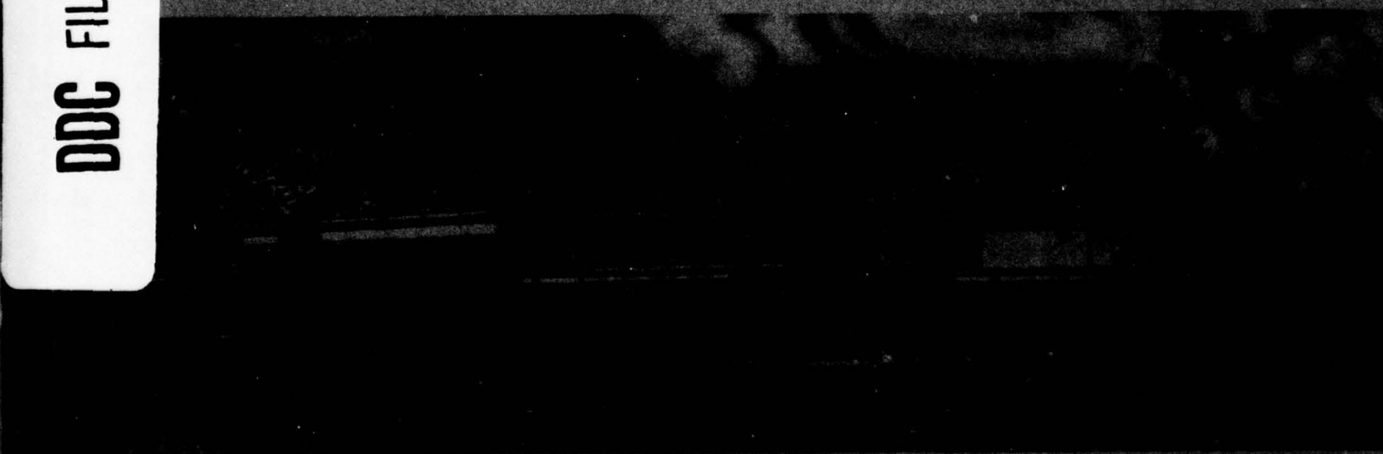

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This report covers the results of a general investigation to determine and demonstrate some of the principles involved in shoaling in harbor entrances and some of the factors to be considered in the development of solutions to the problems. The model used was not a reproduction of a reach of any stream but was designed to fit in an existing facility and provide for two bends and a straight reach between the bends. The model was of the movable-bed type with

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CONT

scales established arbitrarily as 1:400 horizontally and 1:100 vertically. Tests were conducted with the harbor entrance located along the concave bank of the upper bend, in the straight reach, and along the convex bank of the lower bend simultaneously. Results of this investigation ~~provided the following general indications~~: are given in the report.

a. There is a natural tendency for shoaling in entrances to harbors involving openings in bank lines of alluvial streams because of the sudden expansion in channel width and the lowering of the water level causing sediment-laden bottom currents to move toward the opening.

b. The tendency for shoaling in harbor entrances varies with the size of opening in the bank line, the location of the entrance with respect to the channel alignment, and flow conditions.

c. Harbor entrances located along the concave bank of a bend would tend to have less shoaling problems than if located in a straight reach or along the convex side of a bend. Entrances located in straight reaches would tend to have less shoaling problems than those located on the convex side of a bend.

d. Shoaling in harbor entrances depends on the principle of lateral differential in water level. An opening in the bank line required for a harbor entrance tends to cause a lowering of the water level at the entrance. When there is a lowering of the water level on one side of the channel, there is a greater tendency for the slower moving bottom currents with sediment to move toward the lower elevation. Therefore, plans for the elimination or reduction of shoaling in entrances should be designed to reduce the amount of lowering of the water level near the entrance or to prevent the movement of bottom currents toward the lower elevation.

e. Shoaling in harbor entrances located on the concave or convex side of a bend will depend to a considerable extent on the superelevation of the water surface near the entrance which is affected by the curvature of the bend, width of channel, and current velocities during the range of stage and discharge. In general, shoaling will tend to be less with the entrance located downstream of the point bar or axis of the bend.

f. Shoaling in harbor entrances located in straight reaches will depend on the harbor entrance location with respect to the channel over the crossing and the tendency for the channel to be unstable. Channels in long straight reaches will tend to meander between banks and are affected by changes in stages and discharge and the alignment of the channel with respect to the bend upstream.

g. Some reduction in shoaling in harbor entrances can be accomplished by modification of the bank line or with structures near the entrance designed to increase the water level near the entrance, or by structures designed to prevent bottom currents from moving toward the entrance.

h. L-head dikes and in some cases wing dikes, can be used to prevent bottom currents from moving toward the entrance by permitting surface flow over the top of the dikes toward the entrance. The effectiveness of these dikes would depend on their location, length, elevation, and alignment with respect to the entrance and stream channel.

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PREFACE

The model study reported herein was authorized by the President of the Mississippi River Commission (MRC) on 2 May 1968 in a 1st Indorsement to a letter from the U. S. Army Engineer Waterways Experiment Station (WES) to the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD), dated 31 January 1968.

The study recommended by the MRC Potamology Board during its Twenty-First Conference, held on 21 November 1967 as a part of the general potamology investigations, was conducted during the period June 1968 to December 1972. The study was under the general supervision of Messrs. E. P. Fortson (retired) and H. B. Simmons, Chiefs of the Hydraulics Laboratory, and under the direct supervision of Messrs. J. J. Franco (retired), Chief of the Waterways Division, and J. E. Glover, Chief of the Potamology Branch. The engineer in immediate charge of the study was Mr. B. K. Melton (retired) who was assisted by Messrs. A. E. Hullum and R. H. Emerson. This report was prepared by Messrs. Melton and Franco.

During the course of the study, Mr. E. B. Lipscomb, LMVD, visited WES at different times to observe the study and discuss results. Throughout the course of the study monthly progress reports were forwarded to MRC and interim reports to the Committee on Channel Stabilization.

Directors of WES during the study and the preparation and publication of this report were COL Levi A. Brown, CE, COL E. D. Peixotto, CE, COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Directors were Messrs. J. B. Tiffany (retired) and F. R. Brown.

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres

SHOALING IN HARBOR ENTRANCES

Hydraulic Model Investigation

PART I: INTRODUCTION

1. Development of the traffic potential of any navigable stream for commercial and recreational purposes depends to a considerable extent on the availability of slack-water harbors and docking areas. In alluvial streams carrying sediment, there is a natural tendency for deposition to occur in the entrances to harbors and along docking areas involving an opening or setback in the natural bank line. The amount of shoaling and the periodic dredging required to maintain the facilities in a usable condition depends on many factors, including the location of the harbors and docking areas with respect to the alignment of the channel, orientation and dimensions of the entrance, type and amount of sediment carried by the stream, and variations in river stage and discharge.

2. The cost of dredging in harbor entrances or docking areas has been increasing rapidly because of the general lack of disposal areas, the environmental factors that have to be considered, and interference with traffic using the facilities. It is important, therefore, that the elimination or reduction of shoaling to the maximum extent possible be considered in the location, layout, and improvement of harbor facilities.

Principles Involved

3. The movement of sediment in alluvial streams is not continuous from reach to reach but is affected by the sinuosity and irregularities in channel alignment and changes in stages and discharge. Scour and deposition are also affected by the differences in water level across the channel which is based on the Franco principle of lateral differential in water level stated as follows: When conditions are such that a lateral differential in water-surface elevation (or transverse slope)

exists or is produced, there will be a tendency for at least some of the total flow to move toward the lower elevation; the slower moving, sediment-laden bottom currents can make the change in direction easier than the faster moving surface currents which accounts for the tendency of a greater concentration of sediment and deposition toward the lower elevation. This principle provides the third dimension involved in scour and deposition in bends, development of cutoffs and side channels, deposition downstream of dikes, and shoaling in lock approaches and harbor entrances.

4. Lateral differential in water level varies with channel alignment, flow conditions, and changes in channel dimensions. Harbor entrances and docking areas involving an opening or setback in the bank line produce changes in the width of the channel and changes in the local lateral differential in water level. When changes in the alignment of the channel are too abrupt or velocities are too high to make the change in direction toward the lower water level, eddies are formed that can also move sediment toward the area of lower water level.

Need for and Purpose of Model Study

5. Shoaling in harbor entrances, in entrances to slack-water canals, in lock approaches, and in some docking areas located on alluvial streams has been a fairly general problem. Because of the complex nature of alluvial streams and the sedimentation processes involved, little information has been developed that could be used by the design engineer in the development of plans for new harbors or for the improvement of conditions at existing facilities. Since shoaling in harbor entrances depends on many factors, many of which are interrelated, the development of solutions by analytical means that would be generally applicable would be extremely difficult and uncertain. Therefore, a general model study was considered necessary to determine and demonstrate some of the principles involved in the shoaling process and the factors to be considered in the development of solutions to the problem.

PART II: THE MODEL

Description

6. A movable-bed model, reproducing a reach with two alternate bends and a straight reach that could be considered as somewhat typical of the meandering characteristics of alluvial streams, was used for this investigation. The scales of the model were selected to fit in an existing model converted for the purpose. The model bed material consisted of crushed coal with a mean grain diameter of 2.0 mm and specific gravity of 1.30. The model, constructed to scales of 1:400 horizontally and 1:100 vertically (selected arbitrarily), was initially molded to a typical cross section.

Model Adjustment

7. The procedure normally used for the verification of movable-bed models could not be followed in this study since the model was not an exact reproduction of any stream. However, it was essential that the model be adjusted to reproduce movement of bed material and changes in bed configuration similar to that which can be expected in an alluvial stream of the same general characteristics and flow conditions. Therefore, the model was operated by reproducing what could be considered as a typical hydrograph; and adjustments were made in the various hydraulic scale relations and in the rate of introducing bed material until the movement of sediment within the model appeared to be reasonably close to what would be expected in a natural stream of the same general type.

8. After the adjustment, the model was operated for several runs, each run reproducing the hydrograph shown in Plate 1, until the model channel had become reasonably stable. Results of the adjustment test shown in Plate 2 indicate the basic channel configuration before installation of harbor entrances. Deep channels and shallow crossings developed naturally as a result of the flow hydrograph and are typical of developments in alluvial streams with uniform curvature of the bends

and short crossings between bends. These conditions would be found only in alluvial streams with banks stabilized so that the channel would not be free to migrate as is the case in many natural streams.

Test Procedure

9. Tests of improvement plans were concerned with the development of methods or structures that could be used to reduce or eliminate dredging in entrances to harbors at three different locations with respect to channel alignment. The model was operated for these tests by reproducing for each run the same hydrograph (Plate 1) used in the adjustment test. Each test normally consisted of two runs except that some of the plans were tested with several additional runs or until definite trends were indicated, and these plans are referred to as extended testing. In order to establish the rate of shoaling and the problems encountered at each of the three locations, the first test was made with the entrances located normal to the river channel without any attempt to control channel configurations. The model did not reproduce any material in suspension, and the results of tests were based on shoaling caused by material moving along the channel bed.

10. The base test was made to establish the shoaling tendencies in each of the three entrances. In order to provide a better basis for the study, some modifications were made in the channel along the left bank of the upper bend and on the right bank of the lower bend until the amount of shoaling in the entrances was substantial and sufficient to indicate the effectiveness of the proposed plans. For the base test, each of the entrances was placed normal to the channel with entrances being 2080 ft* wide in the upper bend, 1800 ft wide in the straight reach, and 1680 ft wide on the bar side of the lower bend. Although the base test and tests of plans for each of the three locations were tested at the same time, results are covered separately starting with the upper bend and moving downstream.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

PART III: ENTRANCE ALONG CONCAVE BANK

Base Test

Description

11. Shoaling in the entrance to the upper bend was too small with the alignment of the channel developed during the adjustment of the model to provide a reasonable basis for the evaluation of the effectiveness of improvement plans. This condition is attributed to the natural tendency for sediment in bends to move toward the bar side away from the location of the entrance on the concave bank. Accordingly, the bend was modified by adding stone dikes along the concave bank upstream of the entrance until shoaling in the entrance was adequate for the purpose of the study (Plate 3).

Results

12. Results of the base test shown in Plates 3 and 4 indicate that considerable scouring had occurred near the upper bank of the entrance, reaching a depth of 51 ft.* Most of the scoured material moved into the entrance. The shoal area which had depths of less than 10 ft extended more than halfway across the entrance. The greatest shoaling occurred along the right bank of the entrance where deposition was as much as 14 ft above the original bed.

13. The conditions reproduced in the base test were not typical of conditions that would be expected with a harbor entrance located on the concave side of a typical bend. Shoaling in the harbor entrance was induced by the series of stepped-down dikes that were designed to cause sediment to move toward and along the concave bank in the vicinity of the entrance to the harbor located on that side. The movement of sediment into the harbor entrance is a function of the lateral differential in water level which caused a counterclockwise eddy to form with currents moving from the main channel into the entrance channel.

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* Depths are in feet below the assumed mean low water (mlw).

Plan A

Description

14. The first plan tested was designed to reduce the lateral differential in water level between the main channel and entrance channel and reduce or eliminate the eddy and the movement of sediment into the entrance. Accordingly, this plan involved a reduction in the width of the entrance channel by filling along its right bank generally along the outline of the shoal area obtained in the base test (Plate 4). The bottom width of the entrance to the harbor was reduced to 1080 ft.

Results

15. Results of this test (Plate 4) indicated continued shoaling in the entrance extending from the fill in the right bank toward the left bank. The amount of deposition was as much as 10 ft above the original bed and extended farther into the entrance channel than in the base test. The width of the remaining channel between the end of the shoal and the left bank was less than half of the original width but was somewhat deeper. The sandbar opposite the entrance to the harbor had moved toward the entrance and there was some deepening of the river channel along the left bank downstream.

Plan A-1

Description

16. Plan A-1 involved the modification of the river side of the fill of plan A. The alignment of the fill was made nearly parallel to the alignment of the concave bank of the main stream by moving the bank end of the fill away from the entrance (toward the harbor), and a 230-ft-long nonoverflow rock dike extended from about the center of the fill toward the river channel (Plate 4).

Results

17. Results indicate that with plan A-1 there would be a greater tendency for shoaling near the end of the fill (Plate 4). The height of the deposition was as much as 23 ft above the original bed. The

sandbar opposite the entrance did not extend toward the entrance as far as with plan A, and a better channel alignment was obtained in the river channel past the entrance.

Plans B, B-1, B-2, B-3, and B-4

Description

18. Results of previous tests indicated that the shoaling in the entrance was caused principally by the eddy currents moving sediment into the approach. Plan B and modifications were designed to reduce the effects of the eddy with structures and/or modifications of the shape and alignment of the entrance channel. Plan B was the same as the base conditions except for a 1400-ft-long dike extending from the right bank of the entrance channel toward the left bank and angled 60 deg toward the entrance (Plate 4). Modifications of plan B (Plate 5) involved the following:

a. Plan B-1. A 50-ft extension of the dike was added in the entrance channel and the right bank was flared from the dike toward the river on a smooth circular curve.

b. Plan B-2. Same as plan B except that the dike in the entrance channel was angled 45 deg from the alignment of bank and the right bank of the entrance riverward of the dike was moved toward the center, forming an angle of 20 deg.

c. Plan B-3. Same as plan B-2 except that the concave bank of the main channel was moved riverward 400 ft at the entrance, tieing in with the original bank about 2000 ft upstream.

d. Plan B-4. Same as plan B-3 except that a 480-ft-long dike was added within the entrance channel normal to the left bank, leaving an opening between that dike and the angled dike along the right bank of 800 ft.

Results

19. Results shown in Plates 4 and 5 indicate that the structures within the entrance channel with and without modifications in the bank lines as tested in plan B and modifications would not be effective in eliminating shoaling at the upper site.

Plans C, C-1, and C-2

Description

20. Plans A and B were designed to reduce the size and intensity of the eddy in the entrance to the harbor by modifications within and near the entrance channel. Plan C was designed to reduce the lateral differential in water level with structures in the main channel near the harbor entrance. The structures in the main channel were based on the principle used to reduce shoaling in the lower approaches to locks on the Arkansas River and in the entrance to the Chain of Rocks Canal by permitting surface flows to move over the top of the structure, thus preventing bottom currents carrying sediment from moving around the end of the structure and into the entrance channel. Accordingly, plan C and modifications involved the use of an L-head type of dike extending from the bank just upstream and across a portion of the entrance. The features of the plan and modifications (Plate 6) were as follows:

a. Plan C. Same as those at the start of the base test except for the installation of the L-head type of dike extending across a portion of the entrance, leaving an opening between the end of the dike and right bank of the entrance of 1200 ft. The top of the dike was at el 10.*

b. Plan C-1. Same as plan C except that a nonoverflow rock dike was extended from the river end of the right bank of the entrance toward the left bank and angled toward the harbor. The dike formed an angle of 55 deg with the right bank of the entrance downstream, leaving an opening of 1400 ft between the dike and left bank.

c. Plan C-2. Same as plan C except that the dike extended farther into the main channel and extended downstream across the entire entrance. The opening between the end of the dike and adjacent bank was 400 ft.

Results

19. Results of tests of plan C and modifications (Plate 6) indicated considerable scour on the harbor side of the portion of the dike across the entrance. The depth of scour increased with the increase in the length of the dike, varying from a maximum depth of 63 ft with

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* Elevations are in feet above the assumed mlw.

plan C to 80 ft with plan C-2. The depth of scour with plan C-2 was also affected by the dike extending farther out into the river channel. The dike with plan C-2 produced a greater obstruction to flow, causing considerable scour on the river side, particularly at the upper end of the L-section. Shoaling occurred within the entrance channel with plans C and C-1. Most of the shoaling occurred during the lower flows when the dike across the entrance was not overtopped. With plan C-2, the scouring during the higher flows was sufficient to offset any shoaling that would occur around the end of the dike during lower flows. Also, with the narrow opening, the eddy did not extend very far into the entrance channel.

Plans D, D-1, and D-2

Description

20. The conditions for plan D were the same as those for the base test except that the width of the entrance channel was reduced downstream to 1000 ft by moving the left bank of the entrance channel downstream and extending the concave bank of the river channel (Plate 7). Plans D-1 and D-2 were the same as plan D except that L-head type dikes were placed across the entrance extending from the bank of the main channel just upstream of the entrance. The dikes were at el 10 and extended downstream, leaving an opening of 500 ft with plan D-1 and 200 ft with plan D-2 (Plate 7). Plan D-1 extended farther out into the main channel than plan D-2 which accounted for the wider opening.

Results

21. Scouring occurred near the entrance, reaching a depth of 62 ft; and shoaling occurred near the center of the entrance channel, reducing depths to about 5 ft with plan D. Scouring occurred on the river side and entrance side of the dike across the entrance, reaching depths of 60 and 50 ft on the river side and 76 and 70 ft on the entrance side with plans D-1 and D-2, respectively. Shoaling in the entrance continued, reaching a height of 22 ft above the original bed with plan D-1 and 5 ft with plan D-2.

Plans E, E-1, E-2, E-3, and E-4

Description

22. Plan E and modifications (Plates 7 and 8) were as follows:

- a. Plan E. Same as plan D-2 except that the bank line upstream of the entrance was moved riverward about 600 ft and a nonoverflow dike extended from the realigned bank across the entrance channel, leaving an opening between the end of the dike and the riverbank of about 200 ft with a depth of 15 ft (Plate 7).
- b. Plan E-1. Same as plan E except that the dike across the entrance was shortened to provide an opening into the entrance channel of 600 ft (Plate 8).
- c. Plan E-2. Same as plan E-1 except that the riverbank upstream of the entrance was filled to provide a straight bank line for about 1500 ft upstream of the upper bank of the entrance channel.
- d. Plan E-3. Same as plan E-2 except that a low dike extended from the upper end of the nonoverflow dike and angled about 20 deg riverward of the high dike. The dike sloped from el 0.0 at the bank end to el -20 on the river end (Plate 8).
- e. Plan E-4. Same as plan E-3 except that the low dike was removed and high dike was angled riverward along the alignment of the low dike (Plate 8). The riverbank upstream was modified to tie in with the realigned dike.

Results

23. Results of tests of plans E and E-1 indicate no shoaling in the harbor entrance (Plates 7 and 8). Considerable scouring occurred on the harbor side of the dikes reaching depths of more than 50 ft with the two plans. There was also considerable scouring of the channel downstream of the ends of the dikes, reaching depths of 77 and 55 ft with plans E and E-1, respectively.

24. Some shoaling occurred near the junction of the right bank of the entrance channel with the left bank of the main channel with plans E-2 and E-3 reaching a height of about 10 ft above the original bed. A relatively narrow opening of at least 15 ft in depth was maintained between the shoal area and the end of the nonoverflow dike; the opening was somewhat greater with plan E-3. Scouring on the entrance side of the nonoverflow dike reached depths of 50 and 55 ft with plans E-2

and E-3, respectively. There also was scouring riverward and downstream of the end of the nonoverflow dike reaching depths of more than 60 ft with both plans.

25. With plan E-4 there was no shoaling in the entrance channel, but some shoaling occurred along the left bank of the river channel near the entrance and downstream up to elevations of 3 to 5 ft, encroaching on the opening between the bank and the lower end of the dike. In spite of the encroachment, an opening about 800 ft wide was maintained with depths of at least 15 ft. Scouring in the entrance channel reached depths of about 52 ft and scouring riverward and downstream of the end of the dike reached depths of more than 90 ft. Material scoured from the river side of the dike contributed to the shoaling along the left bank downstream of the entrance channel.

Plans F, F-1, F-2, F-3, F-4, F-5, and F-6

Description

26. The features of plan F and modifications (Plates 9 and 10) are outlined as follows:

a. Plan F. Same as plan E-4 except that the nonoverflow dike was oriented to place its lower end 500 ft riverward of the plan D top bank line and provided an opening between the end of the dike and the right bank of the entrance channel of 880 ft at a depth of 15 ft.

b. Plan F-1. Same as plan F except that the nonoverflow dike was extended downstream 400 ft parallel to the main channel alignment, leaving an opening between the end of the dike and far bank of the entrance channel of 500 ft at a depth of 15 ft.

c. Plan F-2. Same as plan F-1 except that the nonoverflow dike and its extension were shifted upstream to provide an opening into the harbor entrance channel of 750 ft at a depth of 15 ft.

d. Plan F-3. Same as plan F-2 except that the nonoverflow dike and extension were shifted upstream to provide a 1000-ft opening into the harbor entrance channel. The end of the dike extension was 480 ft riverward of the plan D bank line.

e. Plan F-4. Same as plan F-1 except that the nonoverflow

dike and extension were shifted downstream and landward to provide an opening into the entrance channel of 450 ft. The alignment of the dike extension was 300 ft riverward of the plan D bank line extended.

f. Plan F-5. Same as plan F-4 except that the nonoverflow dike and extension were farther downstream, reducing the opening into the harbor entrance channel to 250 ft.

g. Plan F-6. Same as plan F-4 except that the nonoverflow dike and extension were shifted upstream to provide an opening into the harbor entrance channel of 650 ft.

Results

27. No shoaling occurred in entrance channel with plans F and F-1 during the first two reproductions of the hydrograph. However, with extended testing considerable shoaling occurred along the right bank of the channel with plan F reaching a height of 21 ft above the original bed and slight shoaling with plan F-1 reaching a height of about 2 ft (depth of 13 ft) as shown in Plate 9. Scouring occurred riverward and downstream of the dike extension, reaching maximum depths of 54 and 58 ft with plans F and F-1, respectively.

28. Shoaling occurred in the entrance channel to an elevation of 5 ft with plan F-2 and a 750-ft opening and to an elevation of 14 ft with plan F-3 and a 1000-ft opening. The shoal area extended from the right bank of the entrance channel toward the left bank, leaving a clear channel width of at least 15 ft in a depth of about 250 ft with plan F-2 and slightly less with plan F-3. Scouring developed riverward and downstream of the end of the dike reaching depths of 56 and 57 ft with plans F-2 and F-3, respectively.

29. Plans F-4, F-5, and F-6 were the same except for the amount of opening into the entrance channel. Shoaling occurred in the harbor entrance channel with each of these plans. The heights of shoals above the riverbed were 8, 18, and 17 ft with plans F-4, F-5, and F-6, respectively. The extent of the shoal areas in each plan was sufficient to adversely affect entrance into the harbor during low flows, particularly with plan F-6.

Plan F-1 with Revised Bank Line

30. Changes in the alignment of the concave bank and elimination of the dikes along the bank upstream of the entrance had little effect on shoaling in the 1000-ft-wide entrance channel (Plates 11 and 12) compared with the original alignment as indicated from the results of test of plan D (Plate 7). However, installation of plan F-1 as tested in the original alignment eliminated shoaling with the nonoverflow dike and the 500-ft opening.

PART IV: HARBOR ENTRANCE IN STRAIGHT REACH

Base Test

Description

31. Straight reaches between bends vary in length and alignment with respect to the bends upstream and downstream. Channels in straight reaches usually cross from one bank to the other and generally are much shallower than channels in bends. The alignment and depth of channels in straight reaches depend on the movement of sediment from upstream, flow conditions, and alignment of the channel approaching the straight reach from the bend upstream. The straight reach in the model was established arbitrarily with the left bank of the reach forming a straight line nearly tangent to the curve in the bank upstream. The base test was conducted with the entrance to the harbor placed normal to the bank and bottom width of the channel of 1800 ft as shown in Plate 3. Because of the alignment of the channel and limited width of the straight reach, controlling depths were greater than those normally encountered over crossings.

Results

32. Results of the base test (Plate 13) indicate shoaling across the entrance extending from the right bank at the junction with the riverbank toward the left bank. All of the shoaling was confined to a narrow strip close along the bank line.

Plans A and A-1

33. Plan A (Plate 13) was the same as that obtained at the end of the base test except that a 1000-ft-long vane dike was placed in the river channel upstream of the entrance. The upper end of the dike was placed 1080 ft from the left bank and the lower end was moved toward the bank to form an angle of about 10 deg landward of the channel line. The dike, with crest at el 15, was designed to cause sediment along the left bank to move riverward away from the harbor entrance. Plan A-1

(Plate 13) was the same as plan A except that the entrance channel width was reduced to 1000 ft by moving the upper bank of the entrance downstream.

Results

34. Results (Plate 13) indicate that with the vane dike of plan A, shoaling occurred across the harbor entrance and riverward of the lower end of the dike. The shoal crossing started upstream of the upper end of the dike, increasing depths along the river side of the dike. Reducing the width of harbor entrance as in plan A-1 had little effect on shoaling across and riverward of the entrance channel (Plate 13).

35. Results of tests of plans A and A-1 indicate that low vane dikes would not be effective in eliminating shoaling affecting the entrance to the harbor. The vane dike would tend to intercept more of the flow and sediment moving along the left bank, some of which moves riverward after passing the lower end of the dike during the lower stages. However, during the higher stages a considerable amount of the surface flow moves riverward over the top of the dike, leaving the sediment on the harbor side of the dike.

Plan B

Description

36. The conditions for plan B were the same as those in the base test except that the width of the entrance channel was 1000 ft, the same as in plan A-1; and a dike was installed near the right bank of the entrance channel. The dike, with crest at el 20, extended from the junction of the lower bank of the entrance channel and the riverbank and was angled 30 deg downstream (Plate 13).

Results

37. Results (Plate 13) indicate shoaling in the entrance, which reduced depths to about 7 ft with some shoaling riverward of the entrance. There was some scouring landward and downstream of the end of the dike.

Plans C and C-1

Description

38. Plan C included a 1000-ft-wide entrance channel and extension of the left bank upstream of the entrance riverward 700 ft (Plate 14). A nonoverflow dike formed an extension of the revised bank across the entrance, leaving a 500-ft opening between the end of the dike and the lower bank.

39. Plan C-1 was the same as plan C except that the left bank extended riverward only 400 ft instead of 700 ft and the nonoverflow dike was shortened 300 ft, leaving an opening to the entrance channel of 560 ft (Plate 14).

Results

40. Results (Plate 14) indicate that scouring occurred along the river side of the revised bank and nonoverflow dike with plan C and shoaling occurred along the left bank downstream of the entrance. The shoal area extended from the end of the dike across the opening to the entrance channel.

41. With plan C-1, scouring occurred riverward of the opening into the entrance channel to a depth of 37 ft with shoaling along the left bank downstream of the opening reaching an elevation of 16 ft after several reproductions of the hydrograph (Plate 14). Some shoaling also occurred along the left bank upstream of the revised bank, but was not sufficient to seriously affect the alignment of the channel approaching the harbor entrance. These results indicate that a 560-ft opening into the entrance channel could be maintained with the features of plan C-1 and the flow conditions reproduced.

Plans D and D-1

Description

42. Plan D was the same as plan C-1 except that a 1000-ft-long dike extended riverward from the junction of the right bank of the entrance channel and left bank of the river channel and angled 35 deg

downstream (Plate 14). The crest of dike sloped from el 15 at the bank to el 5 at the river end.

43. Plan D-1 was the same as plan D except that the sloping dike was replaced with a nonoverflow dike of the same length and alignment (Plate 14).

Results

44. Results of tests of plans D and D-1 indicate that some deposition would occur along the entrance side of the dike downstream of the entrance. The shoaling would tend to reduce the size of the opening into the entrance channel. Extended testing of plan D-1 indicated considerable shoaling along the left bank downstream of the nonoverflow dike with little change in the shoaling along the upstream side of the dike.

Plans D-2, D-3, and D-4

Description

45. Plan D-2 was the same as plan D-1 except that the left bank upstream of the entrance and the dike across the entrance were moved farther riverward 300 ft, leaving an opening into the entrance channel of 700 ft (Plate 15).

46. Plan D-3 was the same as plan D-1 except for a 500-ft-long spur dike which extended riverward from the upper end of the nonoverflow dike across the entrance channel and angled 30 deg from the dike. The spur dike sloped from el 15 on the bank end to el 0 on the river end.

47. Plan D-4 was the same as plan D-3 except that the dike on the downstream side of the entrance channel was removed.

Results

48. Results of test of plan D-2 (Plate 15) indicate scouring along the revised bank and nonoverflow dike upstream of the opening into the entrance channel and some shoaling along the upstream face of the dike downstream of the entrance. Shoaling along the face of the lower dike reduced the width of the opening channel to about 560 ft which was maintained.

49. Modification of the bank line and installation of the sloping dike upstream of the entrance as in plan D-3 increased shoaling on the entrance side of the lower dike which reduced the opening into the entrance channel to less than that obtained with plan D-2 (Plate 15). Removing the lower dike as in plan D-4 caused some shoaling along the left bank just downstream of the entrance, but an opening greater than with plan D-3 was maintained.

Plans D-5 and D-6

Description

50. Plan D-5 was the same as plan C-1 except that the left bank line upstream of the entrance extended riverward 200 ft instead of 400 ft, leaving an opening between the end of the nonoverflow dike and the lower side of the entrance channel of 480 ft. Plan D-6 was the same as plan D-5 except for the addition of a sloping dike angled 30 deg channelward of the nonoverflow dike, the same as in plans D-3 and D-4 (Plate 16).

Results

51. Results (Plate 16) indicate shoaling extending from the lower bank of the entrance channel toward the end of the nonoverflow dike after continued operation with plan D-5. Depths in the opening into the entrance channel were reduced to less than 10 ft by the end of the test. The tendency for shoaling in the opening to the entrance channel was eliminated with the sloping dike of plan D-6. Some scouring occurred in the opening to the entrance channel and along the left bank downstream of the entrance with the latter plan.

52. Plan D-6 was also tested with the revised bank line in the bend upstream. The revision of the bank line caused the channel in the straight reach to cross toward the right bank some distance upstream of the entrance before the installation of plan D-6 (Plates 11 and 17). With the base condition which included the 1000-ft-wide entrance channel, shoaling occurred across the opening to the entrance channel and for some distance riverward of the entrance to depths of less than

10 ft (Plate 17). With plan D-6, the opening to the entrance channel and riverward of the opening maintained depths of at least 15 ft during several reproductions of the hydrograph (Plate 17). There was some erosion of the channel along the left bank downstream of the entrance but depths were less than 10 ft.

PART V: HARBOR ENTRANCE ALONG CONVEX BANK

53. The third harbor entrance tested was located in the bank on the sandbar side of a bend. The bend available for this study was relatively flat (large radius), width of channel bank-to-bank was limited, and flow entered the bend almost tangent to the concave bank (Plate 2). Because of these conditions, the depth of the channel along the concave bank and the size and height of the sandbar along the opposite bank were not as much as would be expected in most bends of alluvial streams. However, shoaling did develop along the convex bank reaching an elevation of 20 ft near the bank. The harbor entrance was located arbitrarily near the center of the bend.

Base Test

Description

54. The base test was conducted with the harbor entrance in place to determine the rate of shoaling that would develop with remedial structures and to provide a basis for comparing the effectiveness of various improvement plans. Accordingly, the entrance channel was placed normal to the channel alignment with an opening in the bank line having a bottom width of 1680 ft with the depth at 15 ft. The sandbar was dredged to a depth of 15 ft with the same width extending from the bank to deep water (Plate 18). The dredged material was removed from the channel.

Results

55. Results (Plate 18) indicate considerable shoaling of the approach channel, particularly along the channel side of the sandbar. Shoaling started along the upstream side of the river end of the dredge cut and moved progressively toward the downstream, leaving an approach channel of less than 10 ft in depth. Shoaling along the upstream side of the approach channel resulted in some scouring along the downstream side, causing the approach channel to angle toward the downstream nearly parallel to the bank line. Flow over the sandbar during high stages produced some scouring in the approach channel near the bank with material deposited in the entrance channel.

Plans A and A-1

56. Plan A was designed to develop the natural tendency for the channel across the sandbar to angle toward the downstream. Accordingly, this plan included an L-shaped dike generally along the alignment developed during the base test (Plate 18). The dike extended 1480 ft from the bank upstream of the entrance channel toward the river channel and then angled about 60 deg toward the downstream. The L-head portion of the dike was 2400 ft long at el 10 compared with el 15 for the portion of the dike extending from the bank. The entrance channel was dredged to a depth of 15 ft generally along the alignment of the dike. The width of the dredged channel at the lower end of the dike was 800 ft.

57. Plan A-1 was the same as plan A except that the dike was raised 5 ft to el 20 and 15 for the two sections (Plate 18).

Results

58. With plan A, sediment moved over the top of the dike and then along the harbor side of the L-head section of the dike. There was some scouring of the bed within the harbor entrance which was deposited in the entrance channel, reducing depths in two small areas to 10 ft (Plate 18). Deposition occurred along the harbor side and downstream of the end of the L-head section of the dike. Only a narrow 10-ft channel was maintained in the approach to the entrance channel along and generally parallel to the left bank of the river channel.

59. Raising of the elevation of the L-head dike 5 ft as in plan A-1 prevented bed material from moving over the top of the dike. Scouring to a depth of 33 ft occurred in the entrance channel just downstream of the portion of the dike normal to the river channel (Plate 18). The material scoured was deposited within the channel, reducing depths in some areas to 12 and 13 ft. Deposition occurred off the end of the L-head section of the dike extending downstream and to the left, reducing the width of the approach channel along the left bank. Scouring in the approach channel just downstream of the end of the dike reached depths of more than 30 ft and a narrow 15-ft approach channel was maintained.

Plans A-2, A-3, and A-4

Description

60. Plan A-2 was the same as plan A-1 except that the portion of the L-head dike extending from the bank was extended riverward 500 ft. The extension sloped from el 10 near the L-head section to el 0 on its river end (Plate 19).

61. Plan A-3 was the same as plan A-1 except that an L-head dike was attached to the river side of the L-head section of the initial dike (Plate 19). The new dike extended 400 ft riverward of the initial dike with the 1000-ft-long L-head section parallel to the L-head section of the first dike. Crest of the new dike was at el 10.

62. Plan A-4 was the same as plan A-3 except that the L-head section of the second dike was angled riverward and sloped from el 10 to 5 (Plate 20).

Results

63. Results of tests of plans A-2, A-3, and A-4 (Plates 19 and 20) indicate the same general trends in that scouring occurred in the approach to the harbor entrance channel. Scouring occurred in the entrance channel and between the lower end of the initial L-head section and the left bank in each case and contributed to shoaling within the entrance channel and in the approach between the end of the dike and the left bank. In general, the modifications of plan A-1, as included in plans A-2, A-3, and A-4, resulted in increased shoaling, particularly in the approach to the harbor entrance.

Plans B, B-1, and B-2

Description

64. Plan B was the same as plan A-1 except that a 6800-ft-long dike was extended from the upper end of the L-head section of the dike at the entrance toward the left bank upstream (Plate 20). The dike was at el 20 and was designed to reduce the amount of flow overtopping the dike near the river end of the harbor entrance channel.

65. Plan B-1 was the same as plan B except that the L-head section of the dike at the end of the entrance channel was raised to el 20, the same as the other portion of the dike (Plate 21).

66. Plan B-2 was the same as plan B-1 except that a dike was placed along the left bank extending from the lower bank of the entrance channel (Plate 21). The dike was at el 15, leaving a 900-ft-wide opening between that dike and the end of the L-head section of the dike at the entrance to the approach channel.

<u>Results</u>

67. Results (Plates 20 and 21) indicate that none of these plans were successful in eliminating shoaling in the approach to the entrance channel. With plan B, considerable erosion of the sandbar occurred along the river side of the dike extending upstream from the upper end of the L-head section at the entrance. The material eroded was moved over the top of the L-head section and deposited along the entrance side of the dike and downstream across the approach. Raising the L-head section of the dike at the harbor entrance as in plan B-1 reduced the amount of sediment moving over the top of the dike and shoaling along and downstream of the end of the L-head section. However, the reduction in shoaling was not sufficient to maintain a satisfactory channel in the approach to the entrance. Installation of the dike along the left side of the approach channel, as in plan B-2, eliminated most of the shoaling along the entrance side of the L-head section with some reduction in the deposition extending from the end of the dike across the approach to the entrance channel. Results with plan B-2 were considerably better than with plans B and B-1 insofar as depths in the approach channel are concerned.

<u>Plans B-3 and B-4</u>

<u>Description</u>

68. Plan B-3 was the same as plan B-2 except that the dike along the right side of the approach channel was raised from el 15 to el 20.

69. Plan B-4 was the same as plan B-3 except that a wing dike was

attached to the L-head section of the dike starting 800 ft downstream of the upper end of the section (Plate 22). The dike was 1180 ft long, angled 30 deg riverward, and sloped from el 20 near the L-head to el 0 at its river end.

Results

70. Results (Plate 22) indicate that raising of the dike along the right side of the approach channel as in plan B-3 reduced the amount of shoaling across the entrance to the approach channel. However, controlling depths across the approach were less than 10 ft over a narrow strip extending from the lower end of the L-head section of the dike across the entrance toward the end of the dike along the right side of the approach channel.

71. The addition of the wing dike as in plan B-4 caused some reduction in shoaling across the approach to the entrance channel where depths ranged from about 12 to more than 15 ft (Plate 22). Flow over the bank end of the L-head dike caused scouring in the entrance channel to a depth of 35 ft. The material scoured was deposited in the entrance channel, reducing depths near the center of the channel to about 10 to 13 ft. Scouring also occurred downstream of the lower end of the L-head dike to a depth of 30 ft.

Plans B-5 and B-6

Description

72. Plan B-5 was the same as plan B-4 except that the dike along the right side of the approach channel was removed and the approach channel was dredged to a width of 800 ft (Plate 23).

73. Plan B-6 was the same as plan B-5 except that the length of the L-head section of the dike across the entrance was reduced 800 ft and the attached wing dike was reduced 60 ft (Plate 23). The approach channel was dredged to provide a minimum width of 1000 ft.

Results

74. Results of tests of plans B-5 and B-6 are shown in Plate 23. With plan B-5, depths of at least 13 ft were maintained in the entrance

and approach channel. Some shoaling had occurred off of the lower end of the L-head section of the dike across the entrance, reducing depths only slightly less than those existing at the start of the test. There was some scouring below the bank end of the L-head dike with shoaling of some 2 ft in the entrance channel along the L-head section.

75. Plan B-6 was tested with several reproductions of the hydrograph with the approach channel dredged before the start of each reproduction. Although there was scouring downstream of the bank section of the L-head dike and shoaling in the entrance channel from material scoured initially, the deposition was practically eliminated during subsequent operation after the scour hole had developed. There was some shoaling along the entrance side of the L-head section of the dike across the entrance and from the end of the dike toward the left bank, leaving a narrow approach channel of poor alignment.

Plans B-7 and B-8

Description

76. Plan B-7 was the same as plan B-6 except that the L-head section of the dike across the entrance was shortened 800 ft. The approach channel was dredged to a minimum width of 1320 ft (Plate 24).

77. Plan B-8 was the same as plan B-6 except that the length of the dike extending from the left bank to the L-head dike was reduced to 3600 ft (Plate 24).

Results

78. Results of tests of plans B-7 and B-8 (Plate 24) show that little or no shoaling occurred in the entrance and approach channel with the initial reproduction of the hydrograph. However, after repeated reproduction of the hydrograph, a large shoal area developed in the approach channel with plan B-7. The shoal was formed by material moving over the top of wing dike.

79. With plan B-8, there was considerable movement of material over the top of the L-head dike causing shoaling along the entrance side of the dike after continued operation. The width of the 15-ft

channel in the entrance was reduced to less than half but adequate depths were maintained in the approach channel up to the end of the test.

Plans B-9 and B-10

Description

80. Plans B-9 and B-10 included the following modifications (Plate 25):

a. Plan B-9 was the same as plan B-8 except that the section of the L-head dike extending from the left bank was removed.

b. Plan B-10 was the same as plan B-8 except that the length of the L-head section was reduced to 1200 ft and the wing dike was moved upstream 400 ft.

Results

81. Results (Plate 25) indicate that removal of the section of the L-head dike extending from the left bank as in plan B-9 would cause erosion of the sandbar upstream of the entrance with the material deposited in the approach channel. With plan B-10, some sediment moved over the top of the L-head dike into the entrance channel; considerable shoaling occurred off the lower end of the dike and extended toward the left bank across the approach channel.

Plans B-11 and B-12

Description

82. The features of plans B-11 and B-12 (Plate 26) were as follows:

a. Plan B-11. Same as plan B-8 except that the section of the L-head dike extending from the left bank was raised to el 25 and the L-head section was raised to el 25 at its upstream end and sloped to el 20. The wing dike was at el 22.5 at the L-head section and sloped to el 0.

b. Plan B-12 was the same as plan B-11 except that the length of the section of the L-head dike extending from the left bank was reduced to 1020 ft and the length of the dike extending from the left bank upstream toward the L-head

dike was reduced to 2440 ft. The approach to the entrance channel was dredged to provide a minimum width of 720 ft.

Results

83. Results of tests of plans B-11 and B-12 are shown in Plate 26. With plan B-11, some material was moved over the top of the L-head dike and deposited close along the entrance side of the dike. However, most of the material passing over the dike was carried across the entrance channel and deposited along the right side of the approach channel and along the left bank downstream. There was some shoaling downstream of the end of the L-head section of the dike across the entrance, but a deep channel of irregular alignment was obtained between the shoal at the end of the dike and the shoal along the left bank downstream.

84. With plan B-12, there was little or no material moving over the top of the L-head dike and little change in the depths in the entrance and approach channel. A reasonably good approach channel was maintained with controlling depths of about 13 ft.

Plans B-13 and B-14

Description

85. The features of plans B-13 and B-14 (Plate 27) were as follows:

a. Plan B-13. Same as plan B-12 except that the river end of the wing dike was raised to el 5.

b. Plan B-14. Same as plan B-13 except that the wing dike was placed at the downstream end of the L-head section with its crest sloping from el 20 to el 0.

Results

86. Results with plan B-13 indicate shoaling across the approach channel extending from the wing dike toward the left bank (Plate 27). There was little change in the depth in the entrance channel. With plan B-14, there was some shoaling extending from the end of the wing dike but a narrow approach channel with controlling depths of 12 ft was indicated between the shoal and the left bank.

Plans B-15 and B-16

Description

87. The features of plans B-15 and B-16 (Plate 28) were as follows:

   a. Plan B-15. Same as plan B-14 except for the addition of a wing dike at the upper end of the L-head section of the dike across the entrance. The wing dike angled 30 deg riverward and sloped from el 20 to 0.

   b. Plan B-16. Same as plan B-15 except that the L-head section of the dike across the entrance was rotated riverward 10 deg and the wing dikes moved accordingly. The length of the upper wing dike was reduced to 800 ft and the lower wing dike to 400 ft. The approach channel was dredged to a minimum width of 1000 ft.

Results

88. Results of tests of plans B-15 and B-16 (Plate 28) indicate that the addition of the second wing dike in plan B-15 eliminated shoaling during the regular test. However, continued operation resulted in the development of a shoal area downstream of the end of the lower wing dike, leaving only a narrow channel of irregular alignment between the shoal and left bank. Changing the alignment of the L-head section of the dike across the entrance and modification of the wing dikes as in plan F-16 increased shoaling downstream of the end of the lower wing dike, completely blocking the approach channel.

Plan B-8, Modified Location

Description

89. The plans tested indicated that the best results were obtained with plans B-4, B-8, and B-12. To determine the effectiveness of one of these plans at a different location, the entrance channel was moved about 5000 ft upstream where the sandbar extended farther riverward from the left bank (Plate 11). Since plan B-8 had indicated reasonably good results after continued operation, it was installed at the new location (Plate 29). Before the plan was installed, a base test was conducted with entrance channel in place and a dredged approach channel

extending riverward normal to the bank line to a depth of 15 ft. The base test was conducted with the channel upstream realigned (Plate 11).

Results

90. Results of the base test (Plate 29) indicate complete blockage of the approach to the entrance channel. The amount of shoaling was considerably greater than that obtained with the entrance located farther downstream as indicated by the results of the base test (Plate 18). With plan B-8 there was little shoaling of the channel during the normal testing period; but with continued testing, shoaling accumulated downstream of the end of the L-head and wing dike leaving controlling depths of only about 3 ft by the end of the test. There was also some scour downstream of the portion of the L-head dike extending from the left bank with the material scoured deposited within the channel.

PART VI: DISCUSSION OF RESULTS AND CONCLUSIONS

Limitations of Model Results

91. Evaluation of the results of this investigation should consider that the model was not a reproduction of any reach of an actual river; therefore the verification of the model which is normally required before studies are undertaken was not possible. The general alignment of the fixed bank lines and width of channel between banks was based on what could be accommodated in an existing facility. The channel configurations were developed by reproducing the flow hydrograph using the scale relations selected arbitrarily to provide adequate movement of the bed material. The model did not reproduce material moving in suspension or the effects of flood stages with overbank flow.

92. Locations and sizes of the harbor entrances were selected arbitrarily and did not reproduce any existing conditions but were designed to develop shoaling problems normally encountered with harbors in alluvial streams. The widths of the entrance channel used were greater in proportion to the width of the stream channel than would normally be encountered. All three of the harbor entrances were tested at the same time, and installation of a plan at one site affected the development of the river channel at that site and the other two sites, particularly where the plan involved structures or modification extending riverward of the bank line. Although some of the plans were tested for a longer period, none of the plans were tested until channel conditions had become reasonably stable. Because of the above and the small linear scales, only a qualitative comparison can be made of the results and relative effectiveness of the various plans.

93. In spite of the limitations mentioned, the study was successful in demonstrating some of the difficulties that can be encountered in maintaining entrances to harbors on alluvial streams, principles involved, effects of the location of the entrance with respect to channel alignment, and factors that have to be considered in developing plans for the reduction or elimination of shoaling.

Summary of Results and Conclusions

94. The following is a summary of results and general indications and conclusions developed during the investigation.

a. There is a natural tendency for shoaling to occur in the entrance to a harbor involving an opening in the bank line of an alluvial stream because of the sudden expansion of the channel width and the tendency for more of the sediment-laden bottom currents to move toward the opening.

b. The movement and deposition of sediment in an alluvial stream are affected by the alignment of the channel which tends to meander and flow conditions. Shoaling in harbor entrances will depend to a considerable extent on their locations with respect to the alignment of the stream channel.

c. Harbor entrances located along the concave bank of a stream bend will tend to have less shoaling problems than if located in a straight reach or on the convex side of the bend because of the tendency for sediment to move away from the concave bank toward the bar side of the channel. The amount of shoaling in an entrance located on the concave side of a bend depends on its location within the bend, channel width between banks, curvature of the bend, and variations in flow conditions.

d. Harbor entrances located on the convex or bar side of a bend will generally be difficult to maintain because of the natural tendency for a point bar to form on that side. The tendency for shoaling will vary with the curvature of the bend, width of channel between banks, variations in flow conditions, and location of the entrance with respect to the bend.

e. Movement of sediment in straight reaches between bends varies with river stage and discharge and is affected by the alignment of the channel leaving the bend upstream and the tendency for the low-water channel to cross from one bank to the other. Generally, shoaling in the entrance to a harbor located in a straight reach will tend to be more than in an entrance located on the concave side of a bend and less than one located on a convex side. The amount of shoaling would depend on its location with respect to the low-water channel and the tendency for the channel to shoal on the entrance side.

f. Shoaling in harbor entrances will also be affected by the size of the opening in the bank line and its effect on currents moving along the bank. Shoaling will tend to

increase with the increase in the width of the opening in the bank line and would tend to be less with the opening angled toward the downstream.

g. Shoaling in harbor entrances depends on the principle of lateral differential in water level. When there is a lowering of the water level on one side of the channel, there is a greater tendency for the slower moving bottom currents and sediment to move toward the lower elevation. An opening in the bank line as required for a harbor entrance tends to lower the water level toward the opening because of the increase in channel width caused by the opening. Plans for the elimination or reduction in shoaling should be designed to reduce the amount of lowering of the water level near the entrance or to prevent the movement of bottom currents toward the entrance.

h. Some increase in water level near the entrance can be accomplished by reduction in the width of the opening, modification of the bank line upstream of the entrance to form a bend away from the entrance, structures designed to change the alignment of the approach to the entrance channel toward the downstream, and/or structures designed to permit sediment-free surface flow into and toward the entrance.

i. Water-surface elevation along the concave bank of a bend will tend to be higher than away from the bank, thus causing the bottom current to move away from the bank. The difference in water level would depend on the radius of the bend, channel width between banks, and velocity of the currents squared. With a short radius bend and relatively high velocities along the bank, the effect of the opening in the bank line might not cause a lowering of the water level sufficiently to cause the bottom currents to move toward the entrance. In such a case, shoaling can only occur from material in suspension and the effects of eddy currents. Modification of the bank line to increase the curvature of the bank would tend to increase the water level near the entrance and reduce the tendency for shoaling.

j. Structures placed within the entrance channel designed to reduce the size of the eddy without other modifications would tend to reduce the effective width of the entrance channel without any appreciable effect on shoaling caused by the movement of bottom currents.

k. The L-head type of dike can be used to reduce the effect of the unfavorable lateral differential in water level near the entrance by permitting surface flow over the top of the structure. The effectiveness of such a structure would depend on its elevation, length, particularly of

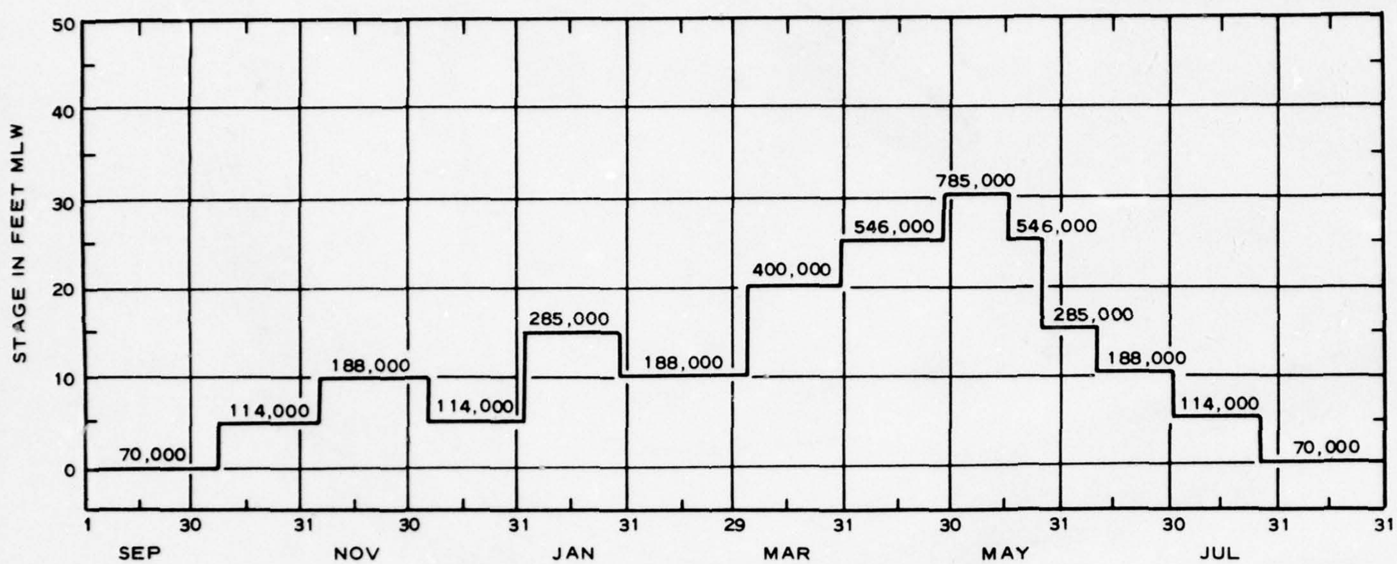
the L-head section, and variations in river stages. Dikes that are too low might permit bottom currents and sediment to move over their tops during some flows. If the dike is too high, there would be no flow over the top during the lower flows and sediment would move around the end of the dike. Also, the L-head section of the dike would have to be long enough to permit sufficient flow over the top and past the end of the dike to prevent bottom currents from moving toward the entrance or approach channel.

l. Flow over the top of L-head dikes would tend to produce scouring along the entrance side which would tend to remove any material that might have been deposited during lower flows. Dikes extending too far into the main channel could produce excessive scouring which could endanger the structure and cause some of the scoured material on the entrance side to be deposited in the entrance channel. Surface flow over the top of the L-head dike would not prevent some deposition of mud and fine silt caused by eddy currents in streams carrying sediment in suspension.

m. Wing dikes angled riverward from the entrance channel can be effective in reducing deposition under some flow conditions, especially when the approach channel is angled toward the downstream and generally parallel to the main channel.

n. An L-head type structure has been successful in eliminating most of the shoaling in the lower entrance to the Chain of Rocks Canal (Mississippi River) during flows that overtop the structure. Wing dikes have been successful in reducing the amount of shoaling and dredging frequency in lower lock approaches on the Arkansas River.

o. Shoaling in harbor entrances varies depending on their size, shape, location with respect to the river channel, characteristics of the streams, and variations in flow conditions. The movement of sediment in the stream, alignment and velocity of currents, variation in river stages, and the effects of the harbor and structures on currents and movement of sediment during all flows should be considered in the design of harbor entrances and associated structures. Because of the many variables involved, the design of harbors or harbor entrances or the design of modifications for the reduction of shoaling problems should be based on the results of model studies. With a model study, the relative effectiveness of various plans and modifications can be determined and the optimum solution assured.



NOTE: VALUES SHOWN ON HYDROGRAPH ARE PROTOTYPE DISCHARGE IN CFS.

STAGE-DISCHARGE HYDROGRAPH

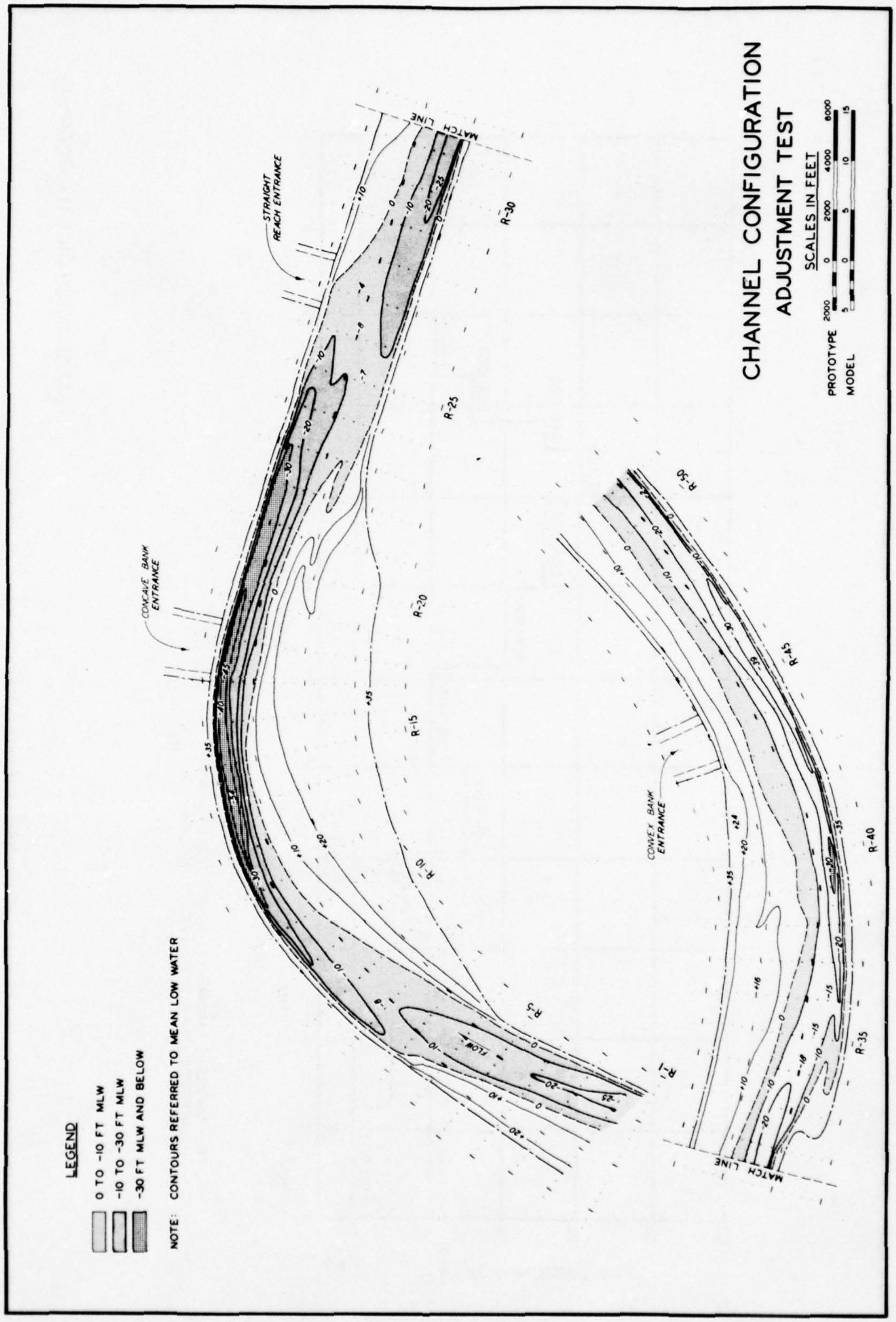

CHANNEL CONFIGURATION
ADJUSTMENT TEST
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
0 TO -10 FT MLW
-10 TO -30 FT MLW
-30 FT MLW AND BELOW
NOTE: CONTOURS REFERRED TO MEAN LOW WATER
STRAIGHT REACH ENTRANCE
CONCAVE BANK ENTRANCE
CONVEX BANK ENTRANCE
MATCH LINE
MATCH LINE
FLOW

PLATE 2

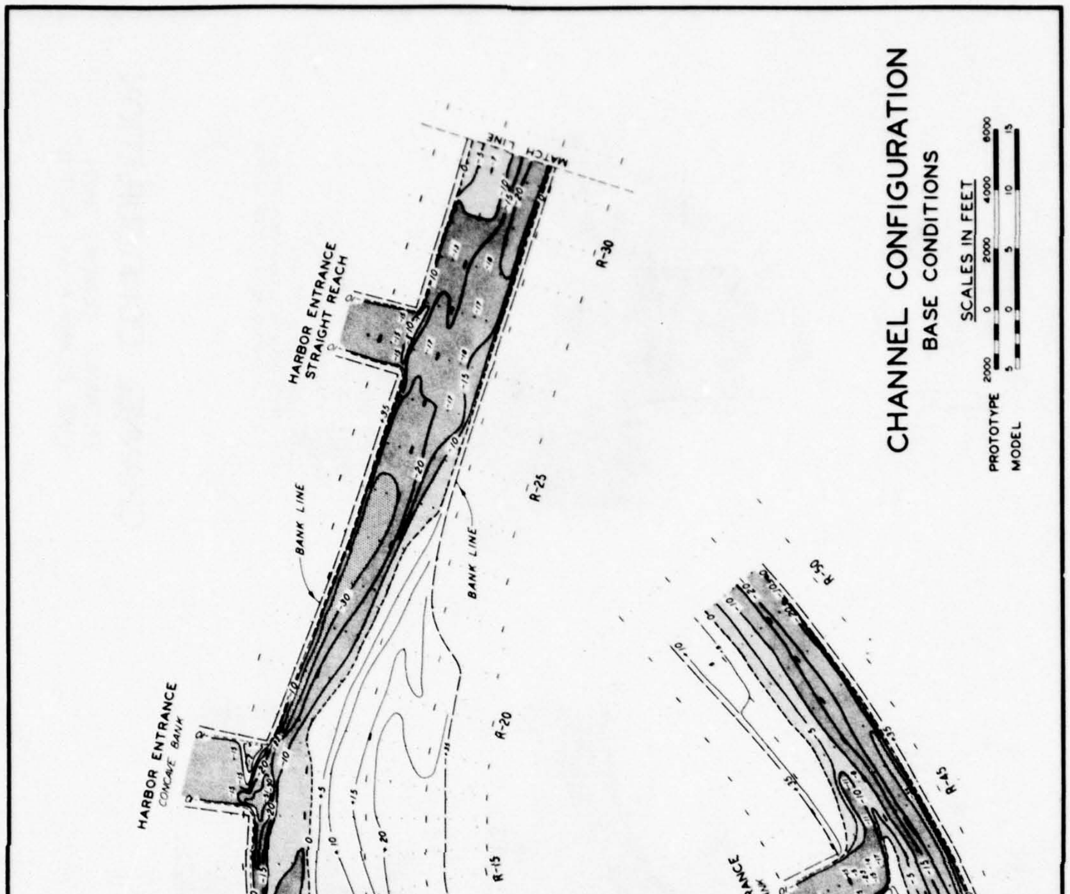
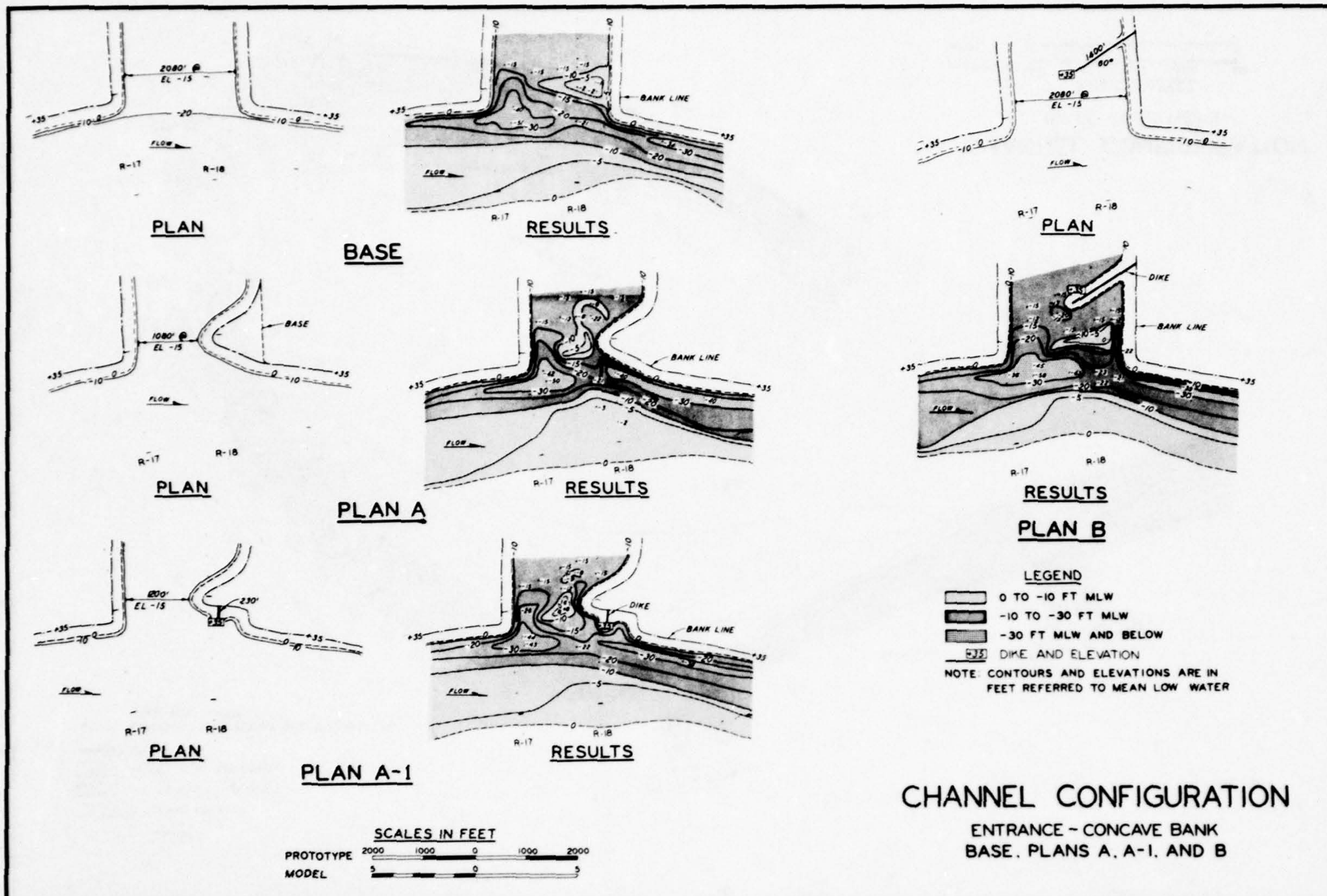

CHANNEL CONFIGURATION
BASE CONDITIONS
SCALES IN FEET
PROTOTYPE 2000 0 2000 4000 6000
MODEL 5 0 5 10 15
LEGEND
0 TO -10 FT MLW
-10 TO -30 FT MLW
-30 FT MLW AND BELOW
DIKE
NOTE: CONTOURS AND ELEVATIONS REFERRED TO MEAN LOW WATER
HARBOR ENTRANCE STRAIGHT REACH
HARBOR ENTRANCE CONCAVE BANK
HARBOR ENTRANCE CONVEX BANK
BANK LINE
MATCH LINE
DIKE ELEVATIONS
FLOW
R-5
R-10
R-15
R-20
R-25
R-30
R-35
R-40
R-45
R-50

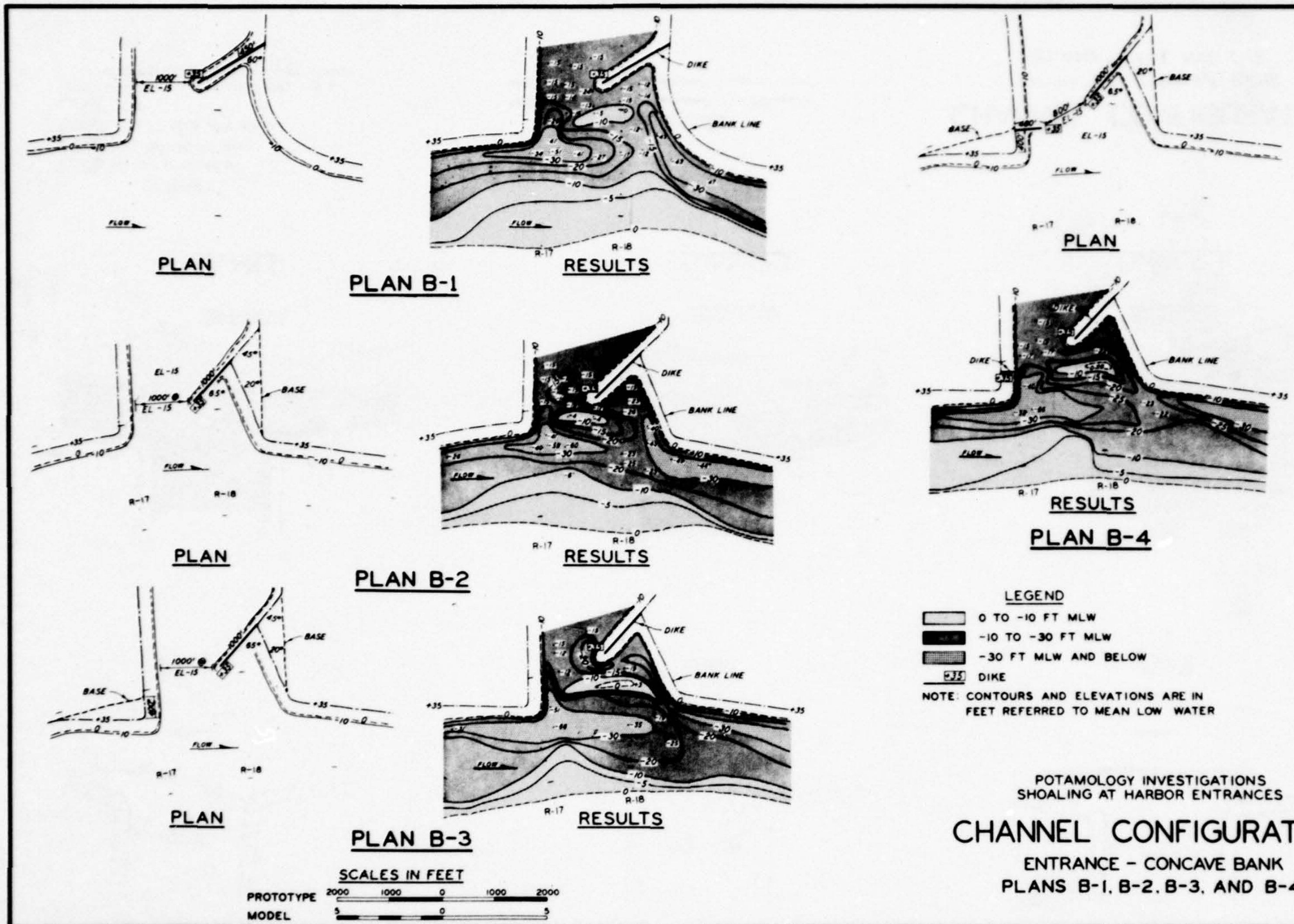
PLATE 4



CHANNEL CONFIGURATION

ENTRANCE - CONCAVE BANK

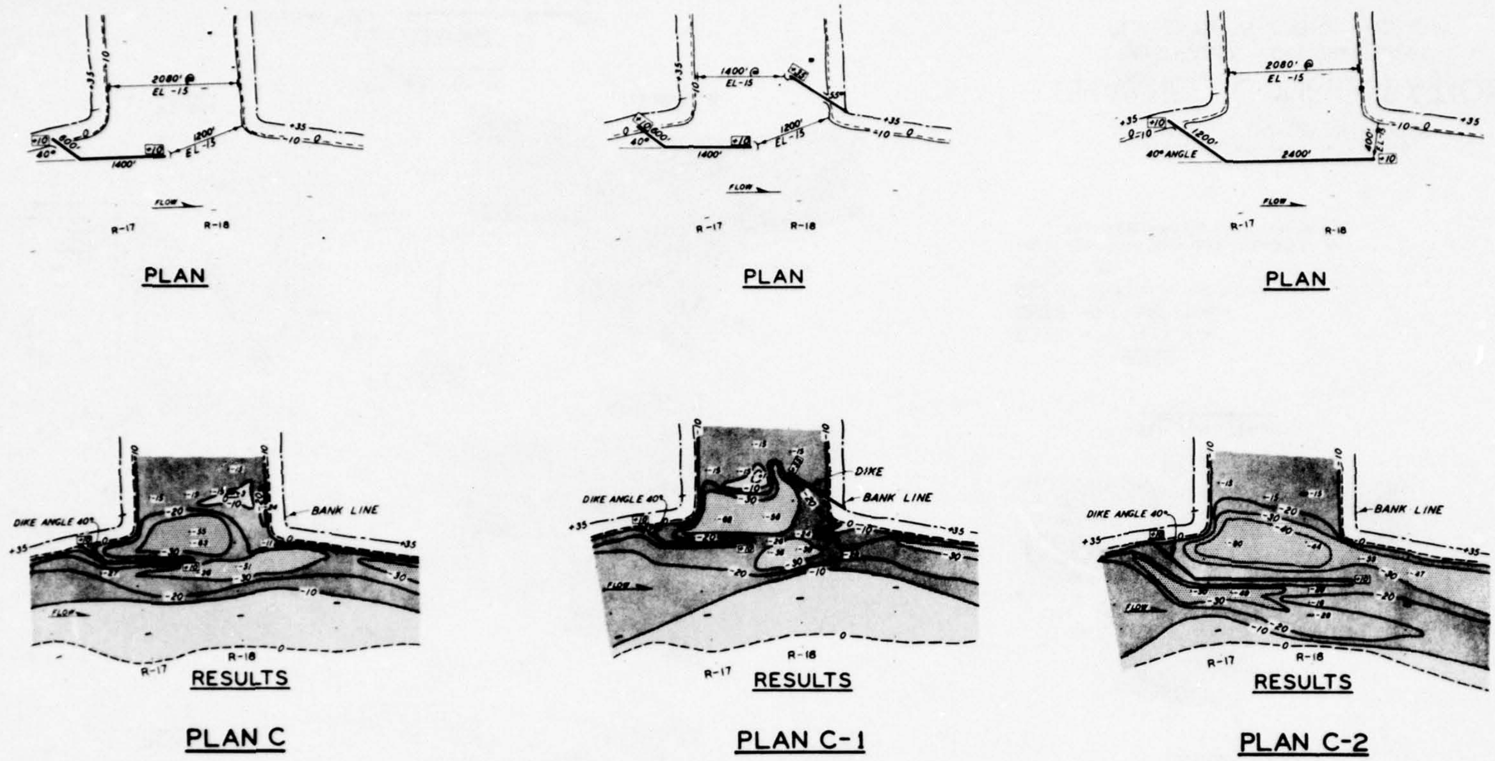
BASE, PLANS A, A-1, AND B



POTAMOLOGY INVESTIGATIONS
SHOALING AT HARBOR ENTRANCES

CHANNEL CONFIGURATION

ENTRANCE - CONCAVE BANK
PLANS B-1, B-2, B-3, AND B-4



LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

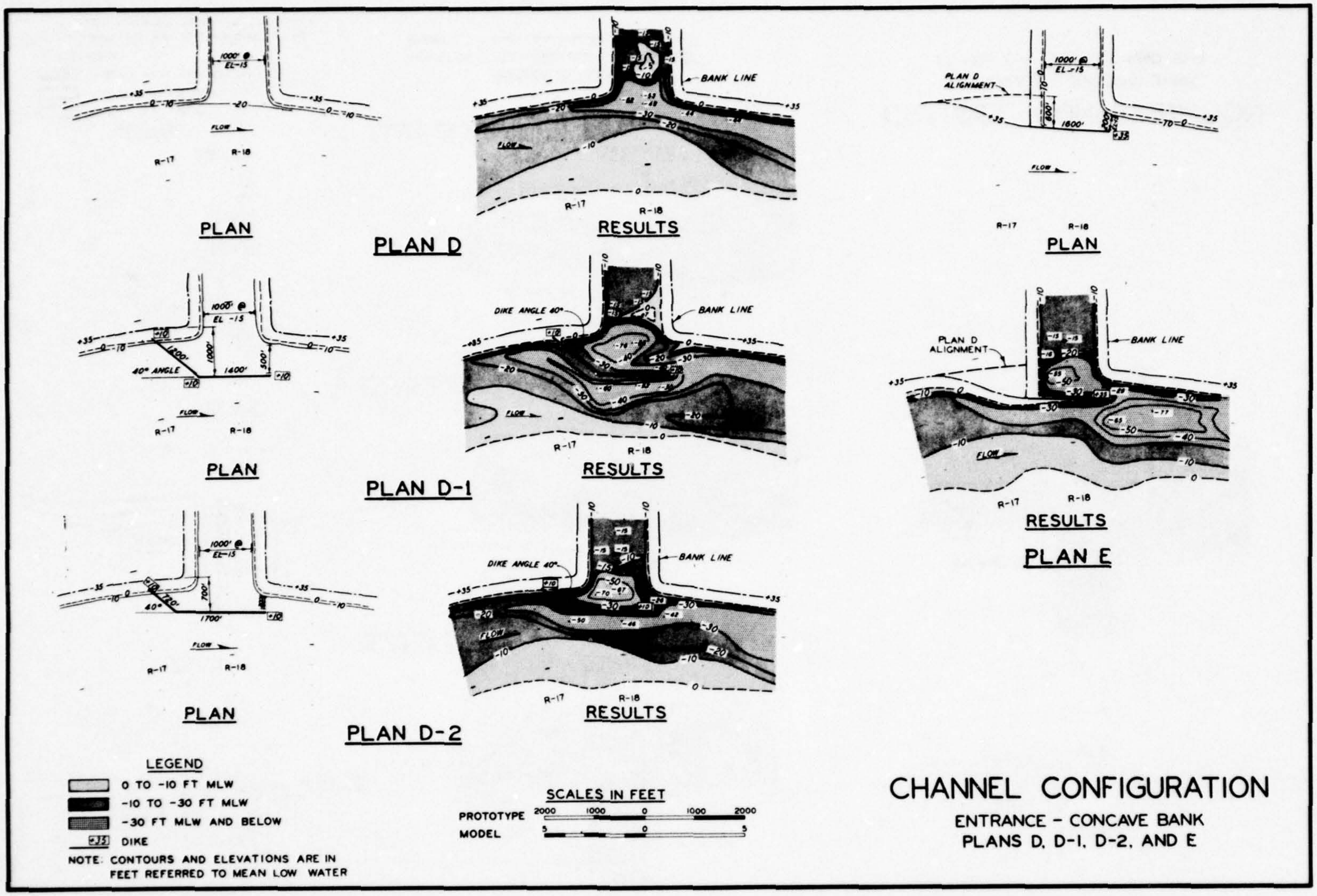
PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

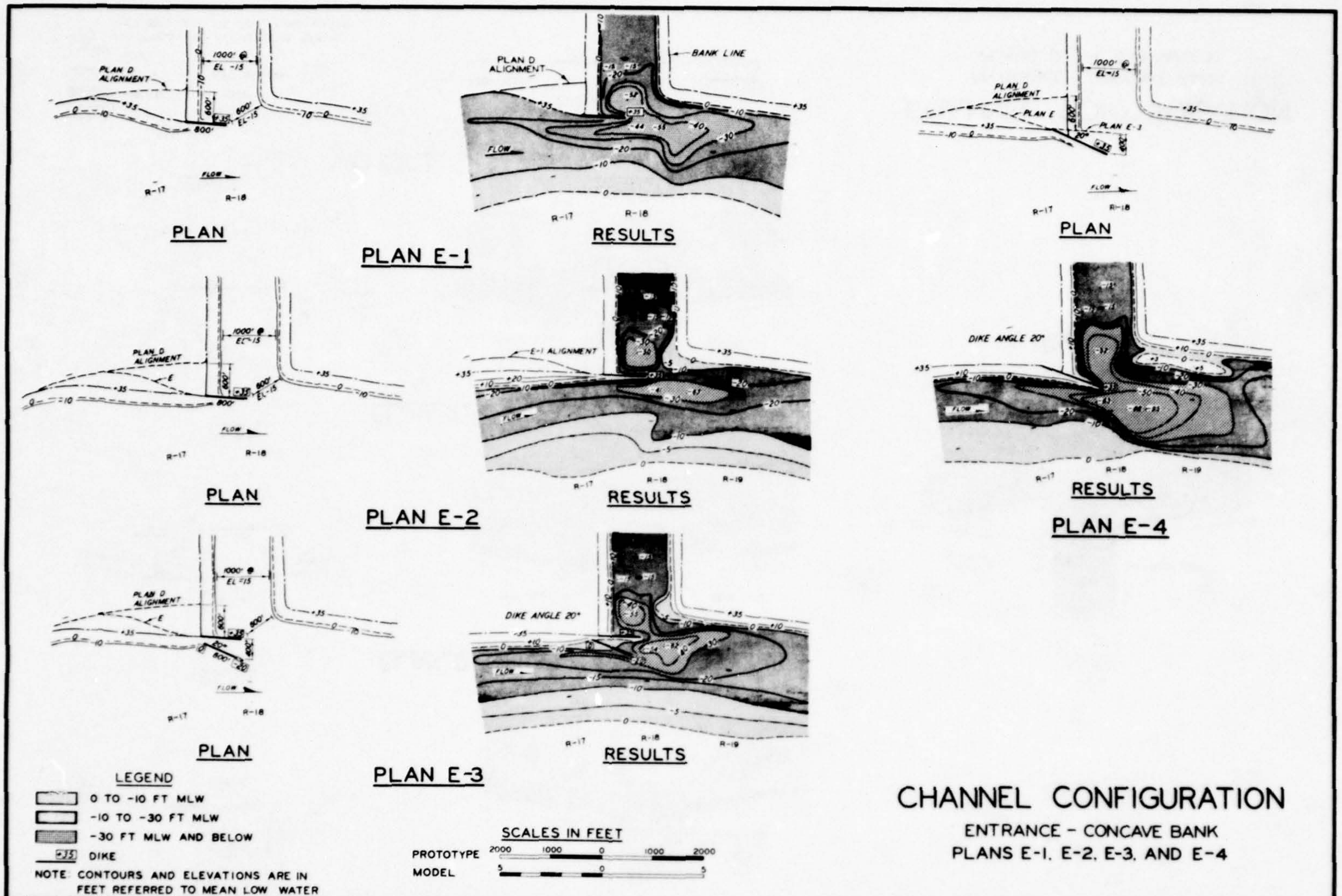
CHANNEL CONFIGURATION

ENTRANCE - CONCAVE BANK

PLANS C, C-1, AND C-2

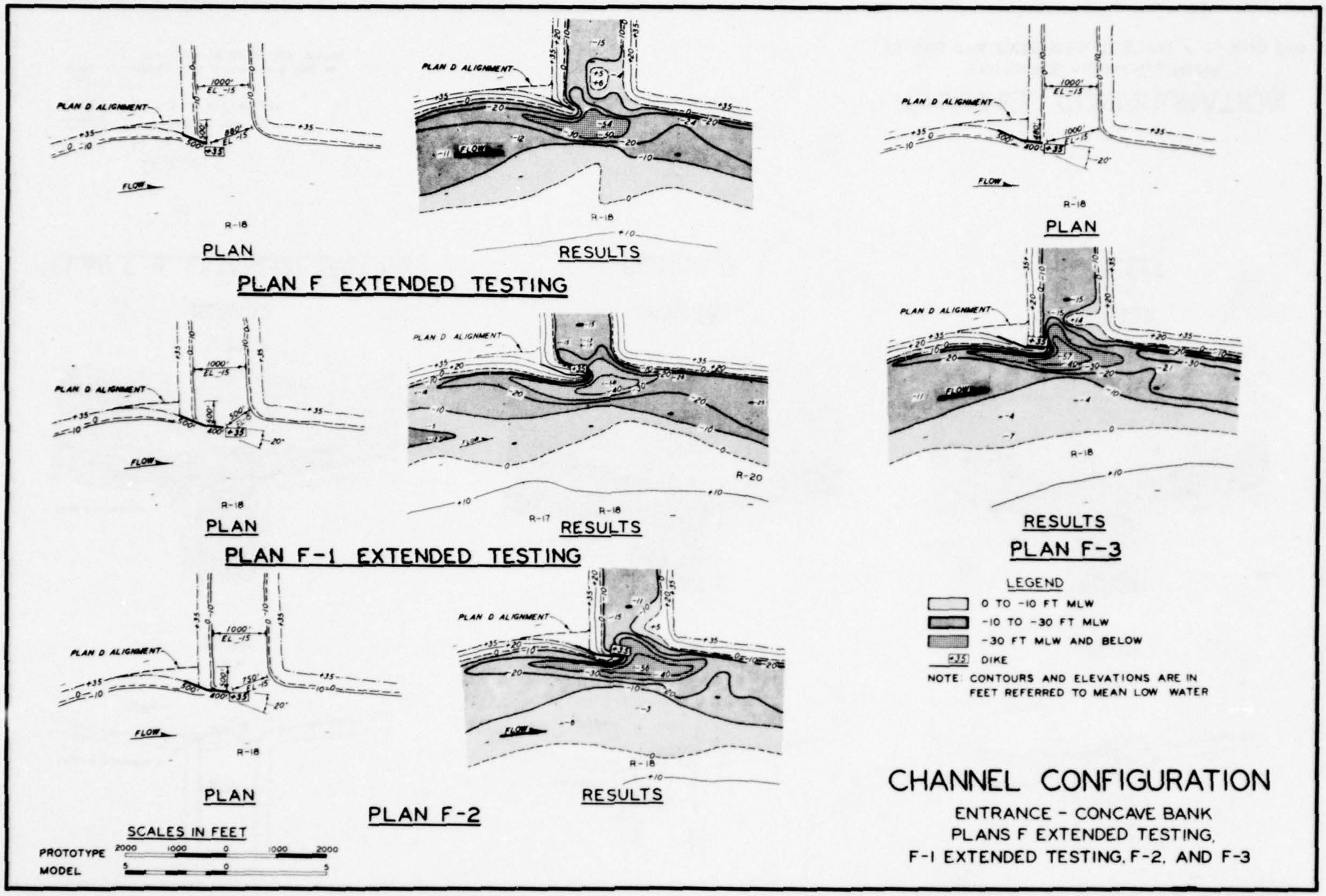


CHANNEL CONFIGURATION
ENTRANCE - CONCAVE BANK
PLANS D, D-1, D-2, AND E



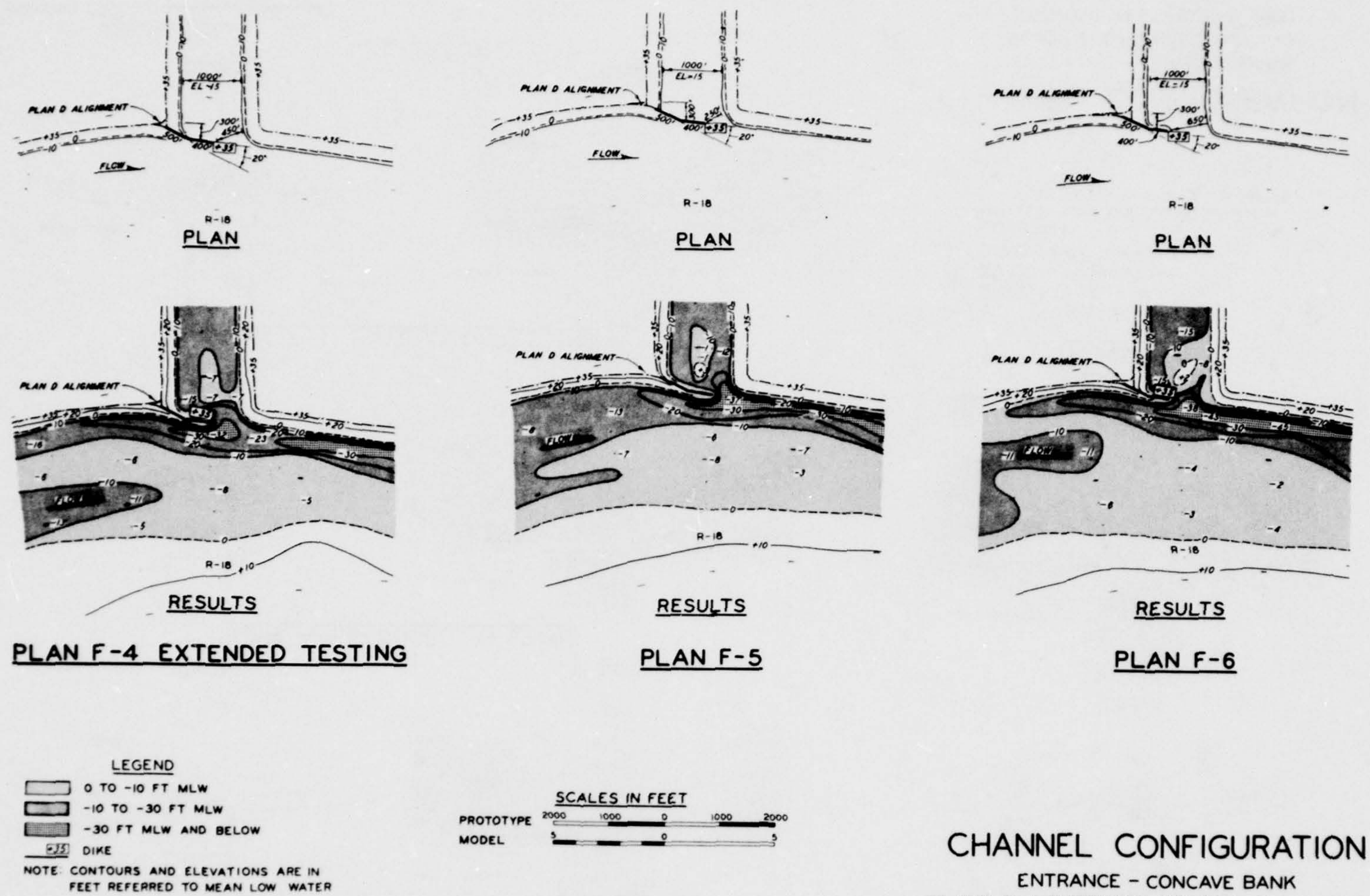
CHANNEL CONFIGURATION
ENTRANCE - CONCAVE BANK
PLANS E-1, E-2, E-3, AND E-4

PLATE 8



CHANNEL CONFIGURATION

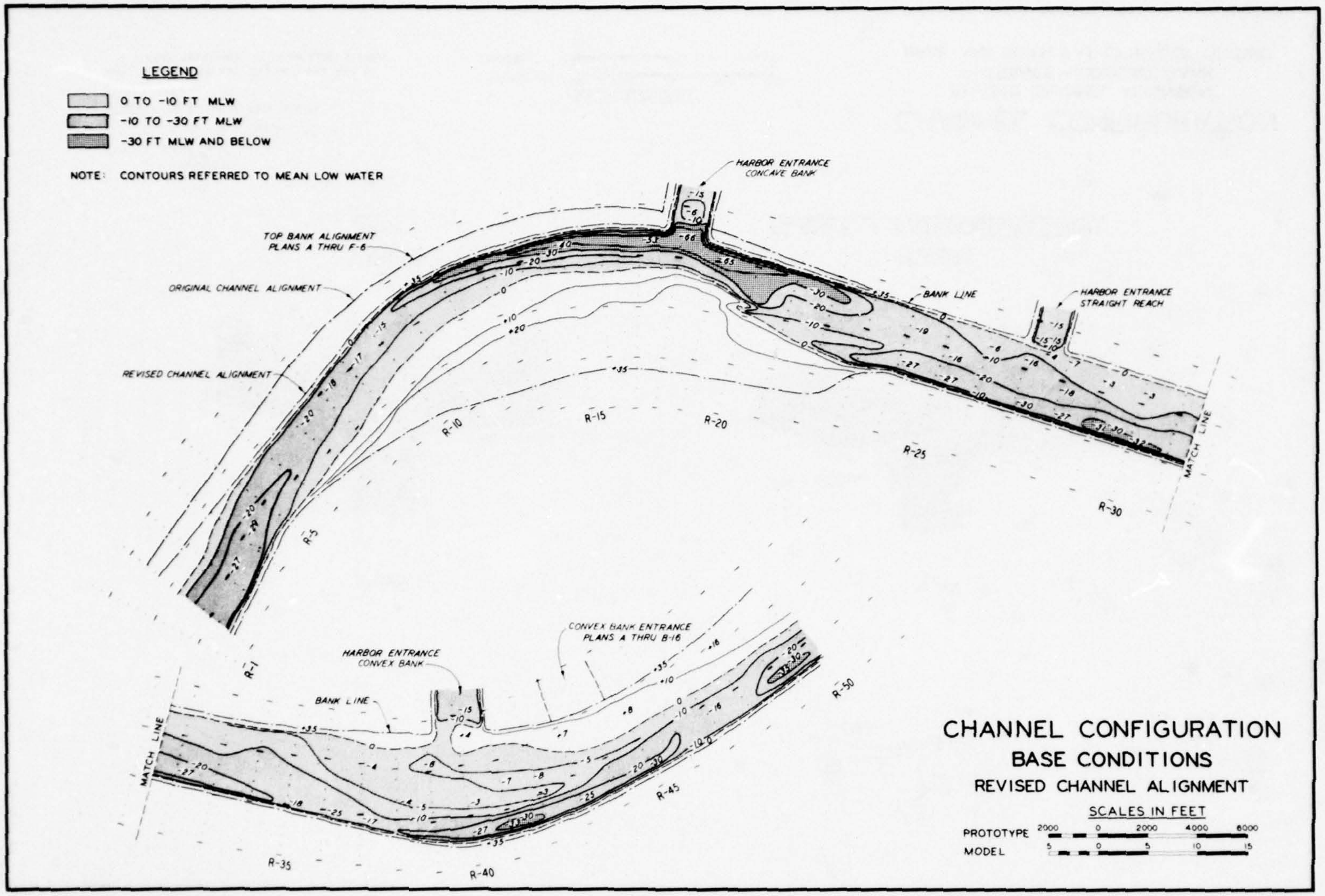
ENTRANCE - CONCAVE BANK
PLANS F EXTENDED TESTING,
F-1 EXTENDED TESTING, F-2, AND F-3



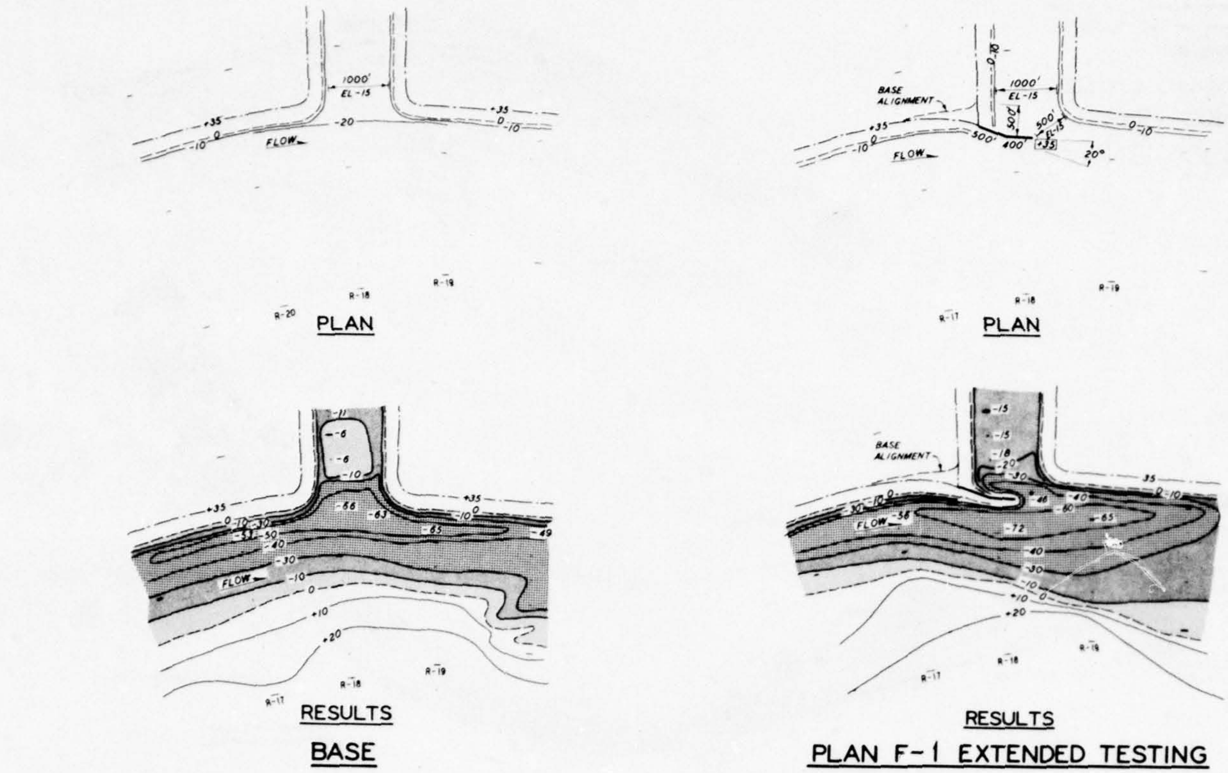
CHANNEL CONFIGURATION

ENTRANCE - CONCAVE BANK

PLANS F-4 EXTENDED TESTING, F-5, AND F-6



CHANNEL CONFIGURATION
BASE CONDITIONS
REVISED CHANNEL ALIGNMENT



LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

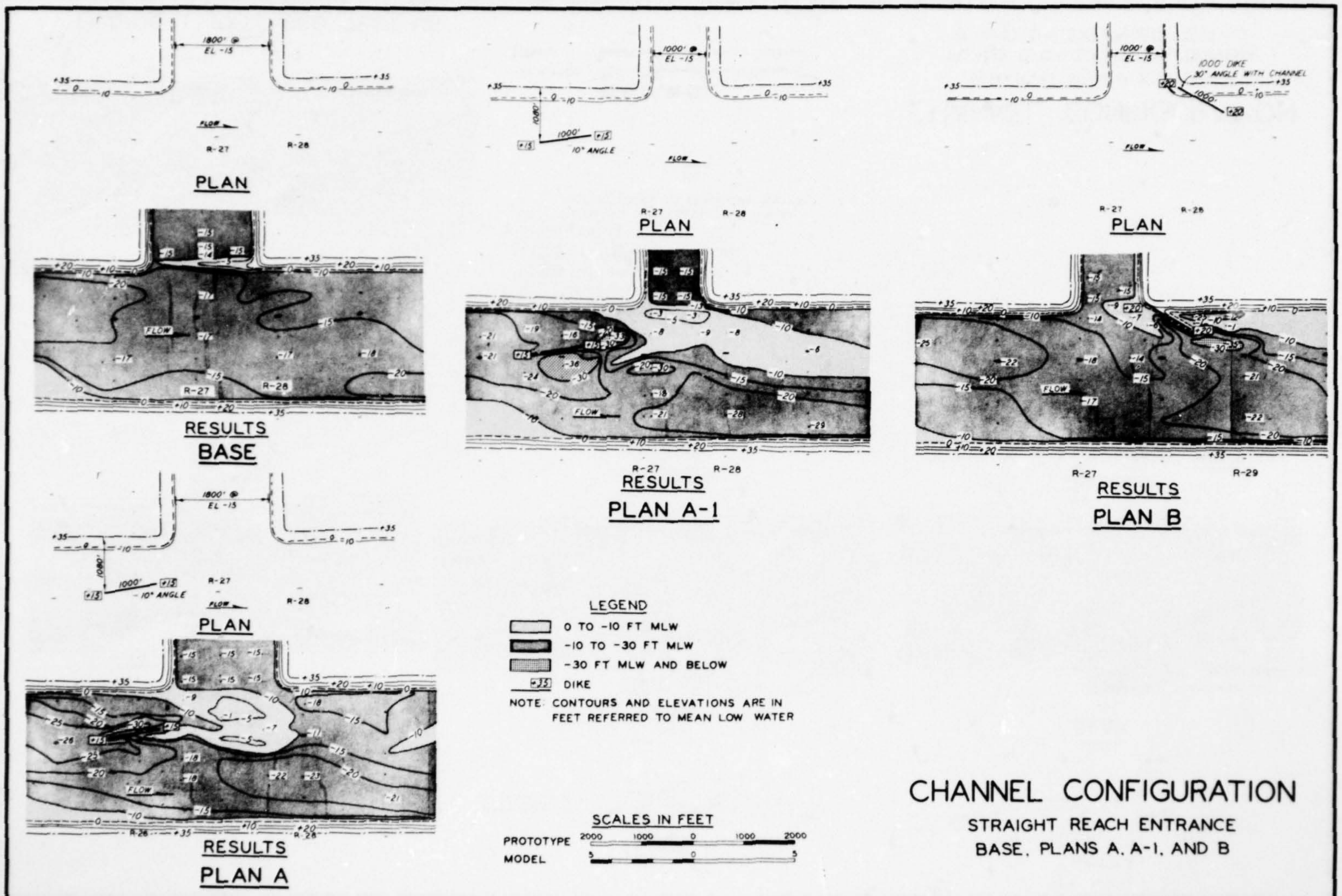
SCALES IN FEET

PROTOTYPE 2000 1000 0 1000 2000

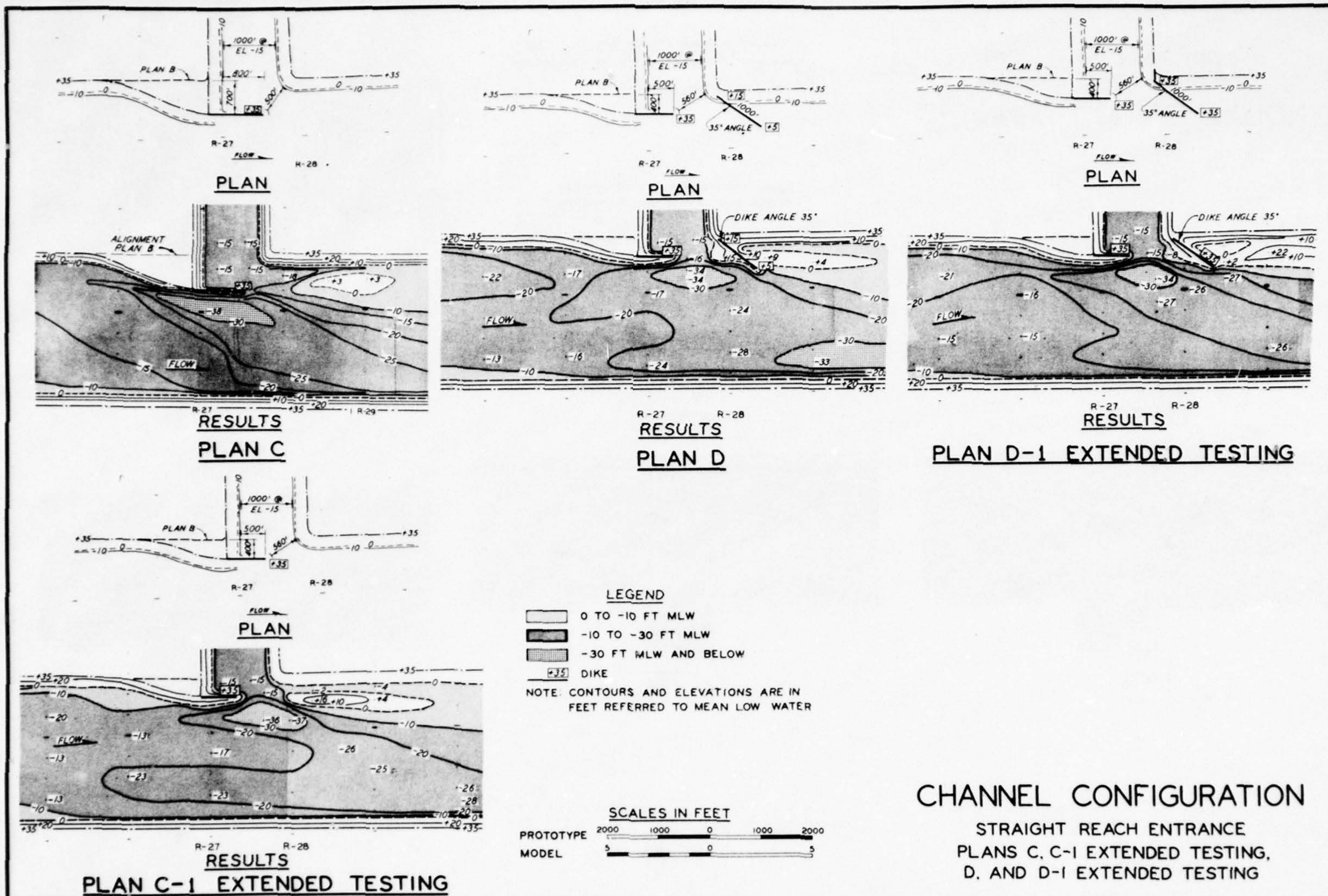
MODEL 5 0 5

CHANNEL CONFIGURATION

REVISED CHANNEL ALIGNMENT
ENTRANCE - CONCAVE BANK
BASE AND PLAN F-1 EXTENDED TESTING

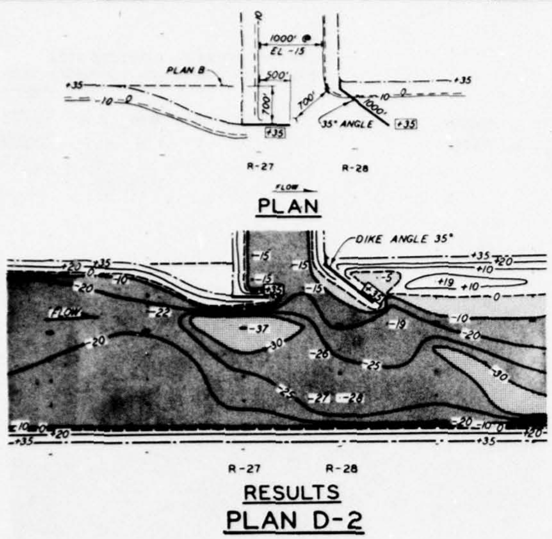


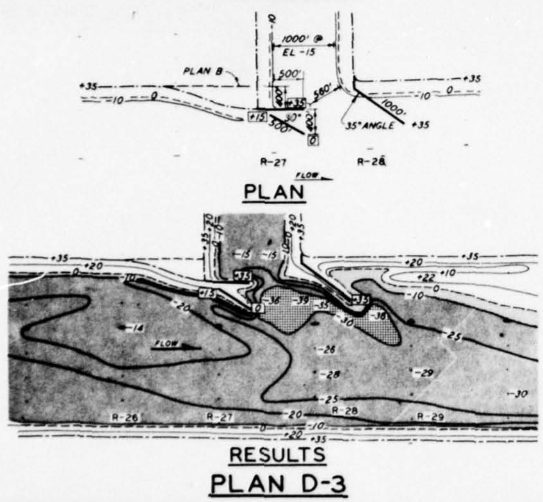
CHANNEL CONFIGURATION
STRAIGHT REACH ENTRANCE
BASE, PLANS A, A-1, AND B

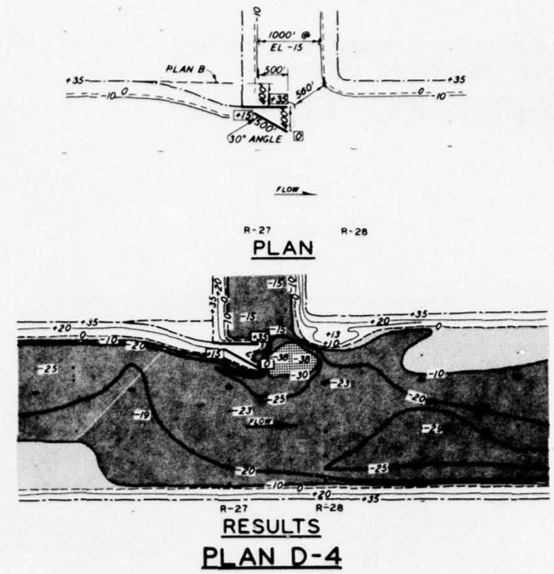


CHANNEL CONFIGURATION

STRAIGHT REACH ENTRANCE
PLANS C, C-1 EXTENDED TESTING,
D, AND D-1 EXTENDED TESTING







LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

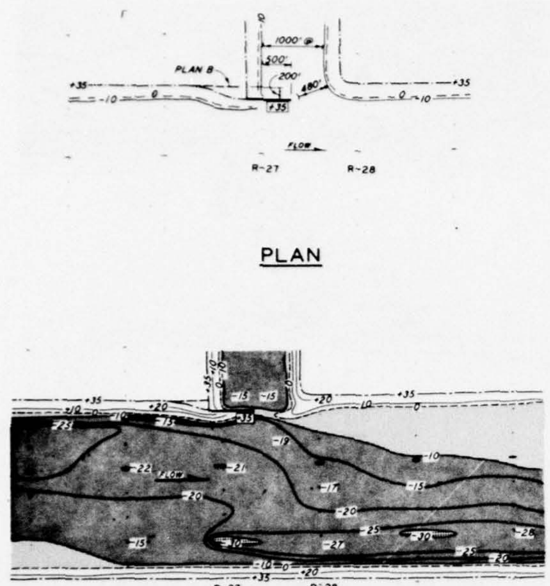
SCALES IN FEET

PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

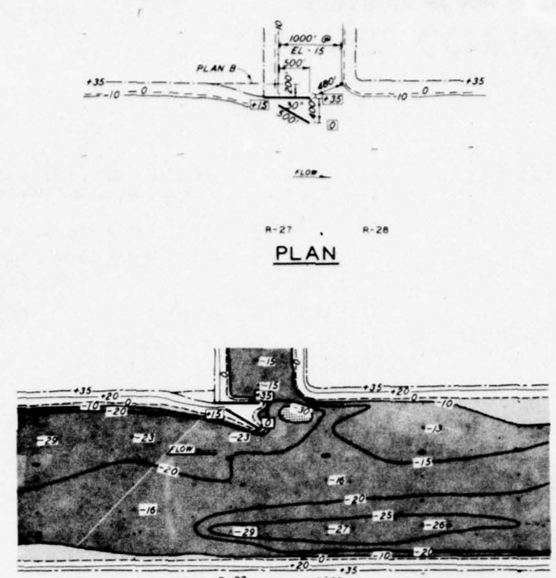
STRAIGHT REACH ENTRANCE
PLANS D-2, D-3, AND D-4



PLAN

RESULTS

PLAN D-5



PLAN

RESULTS

PLAN D-6 EXTENDED TESTING

LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

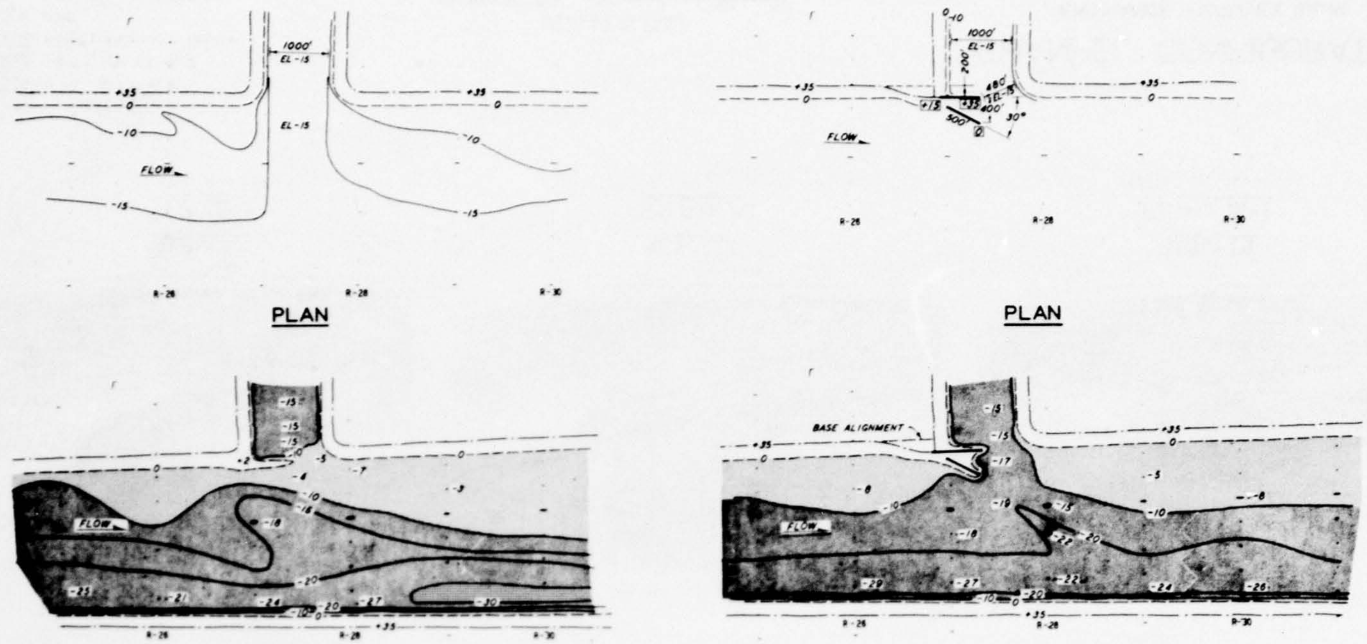
PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

STRAIGHT REACH ENTRANCE

PLANS D-5 AND D-6 EXTENDED TESTING



PLAN

PLAN

RESULTS

BASE

RESULTS

PLAN D-6 EXTENDED TESTING

LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

REVISED CHANNEL ALIGNMENT
STRAIGHT REACH ENTRANCE
BASE, AND PLAN D-6 EXTENDED TESTING

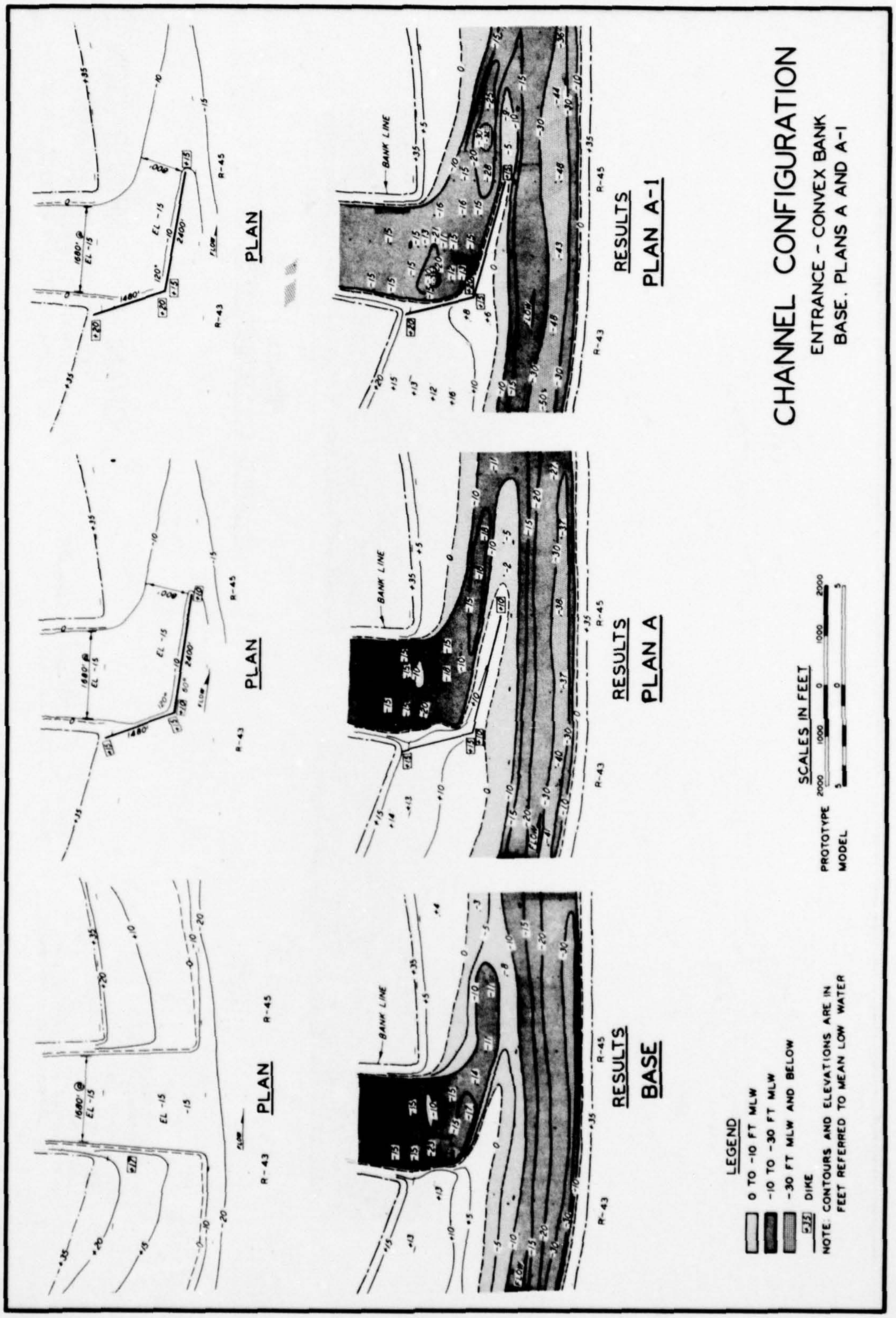
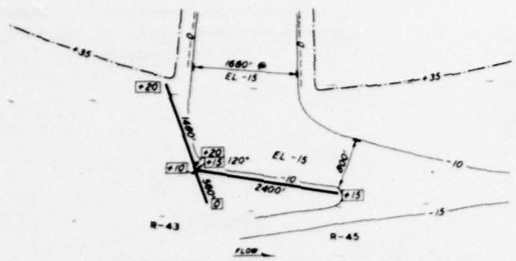
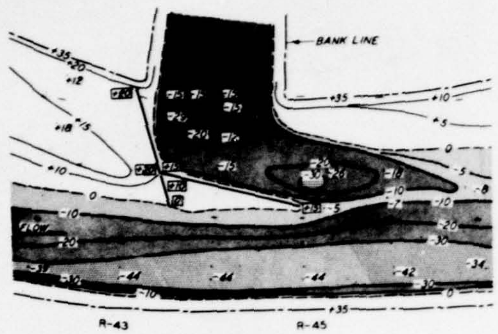

CHANNEL CONFIGURATION
ENTRANCE - CONVEX BANK
BASE, PLANS A AND A-1
PLAN
RESULTS
BASE
PLAN
RESULTS
PLAN A
PLAN
RESULTS
PLAN A-1
BANK LINE
R-43
R-45
FLOW
LEGEND
0 TO -10 FT MLW
-10 TO -30 FT MLW
-30 FT MLW AND BELOW
DIKE
NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER
SCALES IN FEET
PROTOTYPE 2000 1000 0 1000 2000
MODEL 5 0 5

PLATE 18

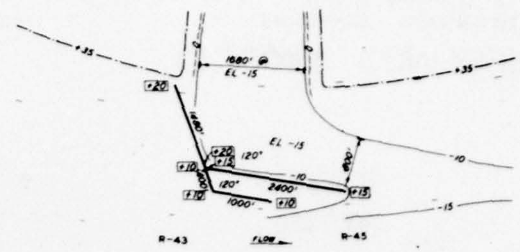


PLAN

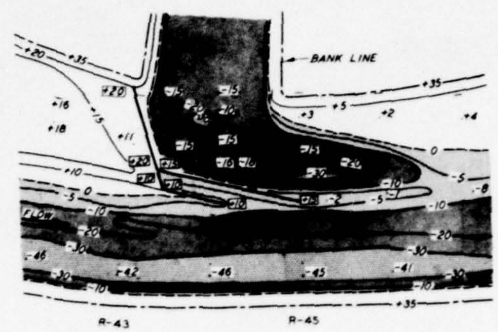


RESULTS

PLAN A-2



PLAN



RESULTS

PLAN A-3

LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

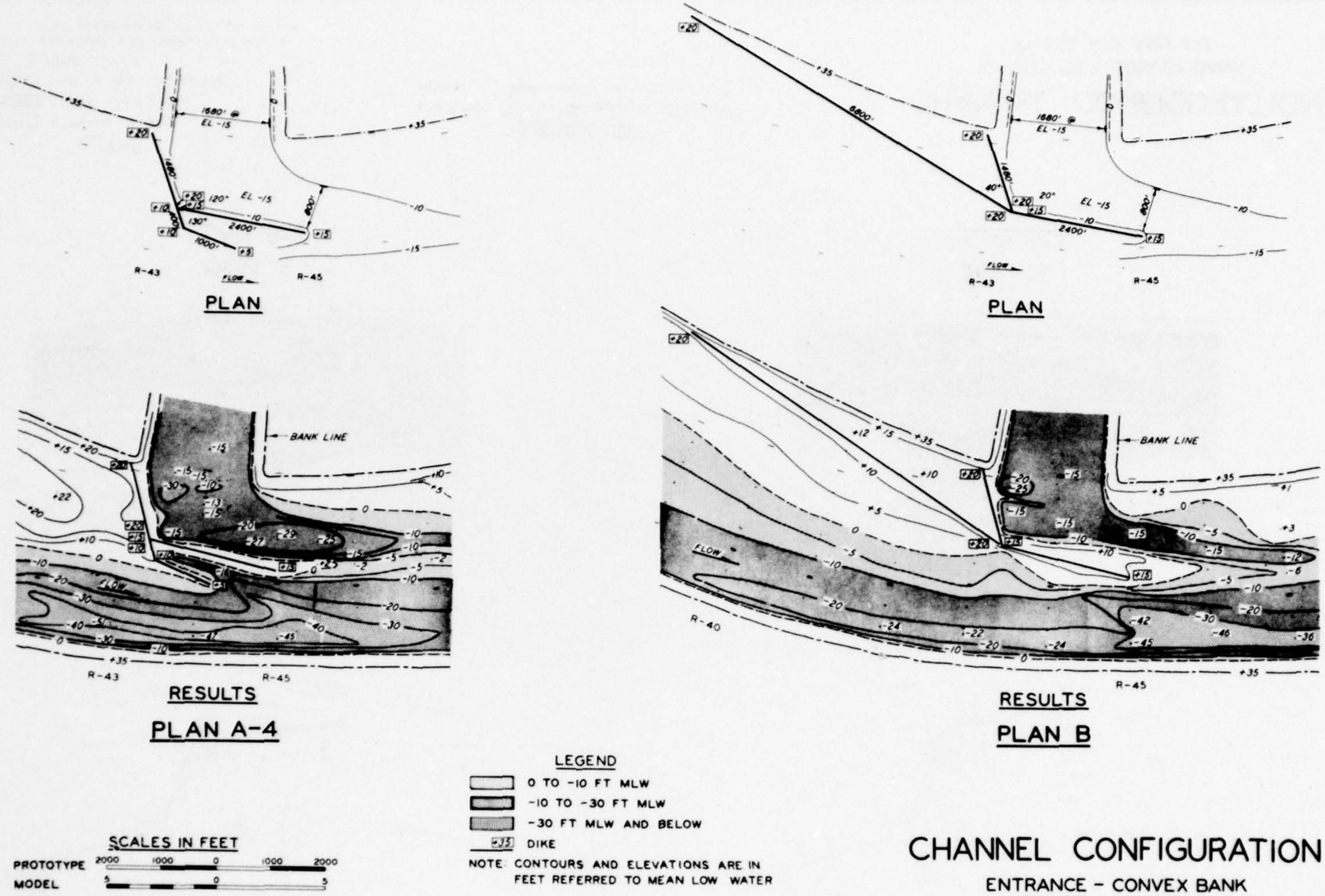
PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK

PLANS A-2 AND A-3



CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK
PLANS A-4 AND B

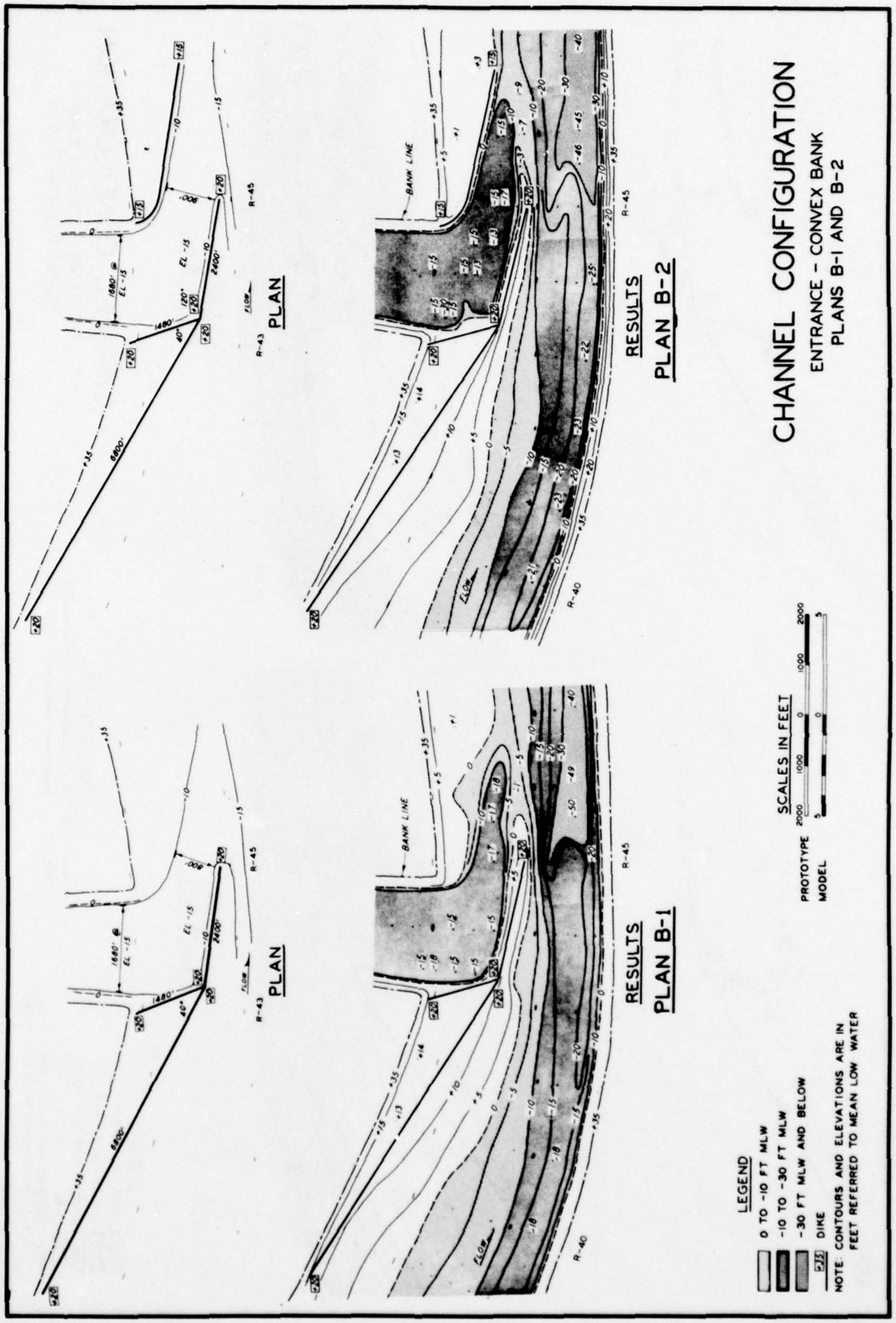
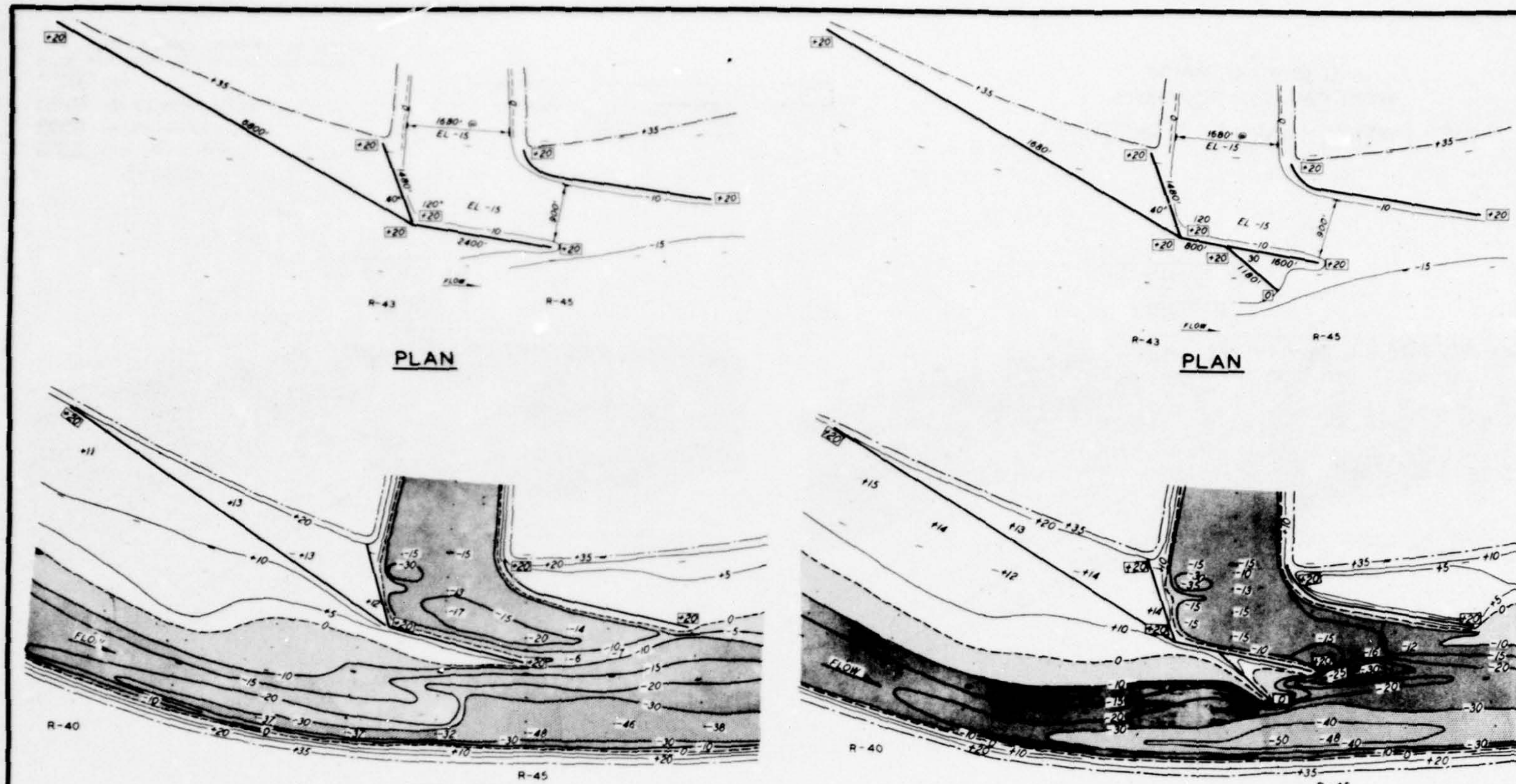

CHANNEL CONFIGURATION
ENTRANCE - CONVEX BANK
PLANS B-1 AND B-2
PLAN
RESULTS
PLAN B-1
PLAN
RESULTS
PLAN B-2
BANK LINE
FLOW
R-40
R-43
R-45
LEGEND
0 TO -10 FT MLW
-10 TO -30 FT MLW
-30 FT MLW AND BELOW
DIKE
NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER
SCALES IN FEET
PROTOTYPE
MODEL

PLATE 21



RESULTS
PLAN B-3

RESULTS
PLAN B-4

LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

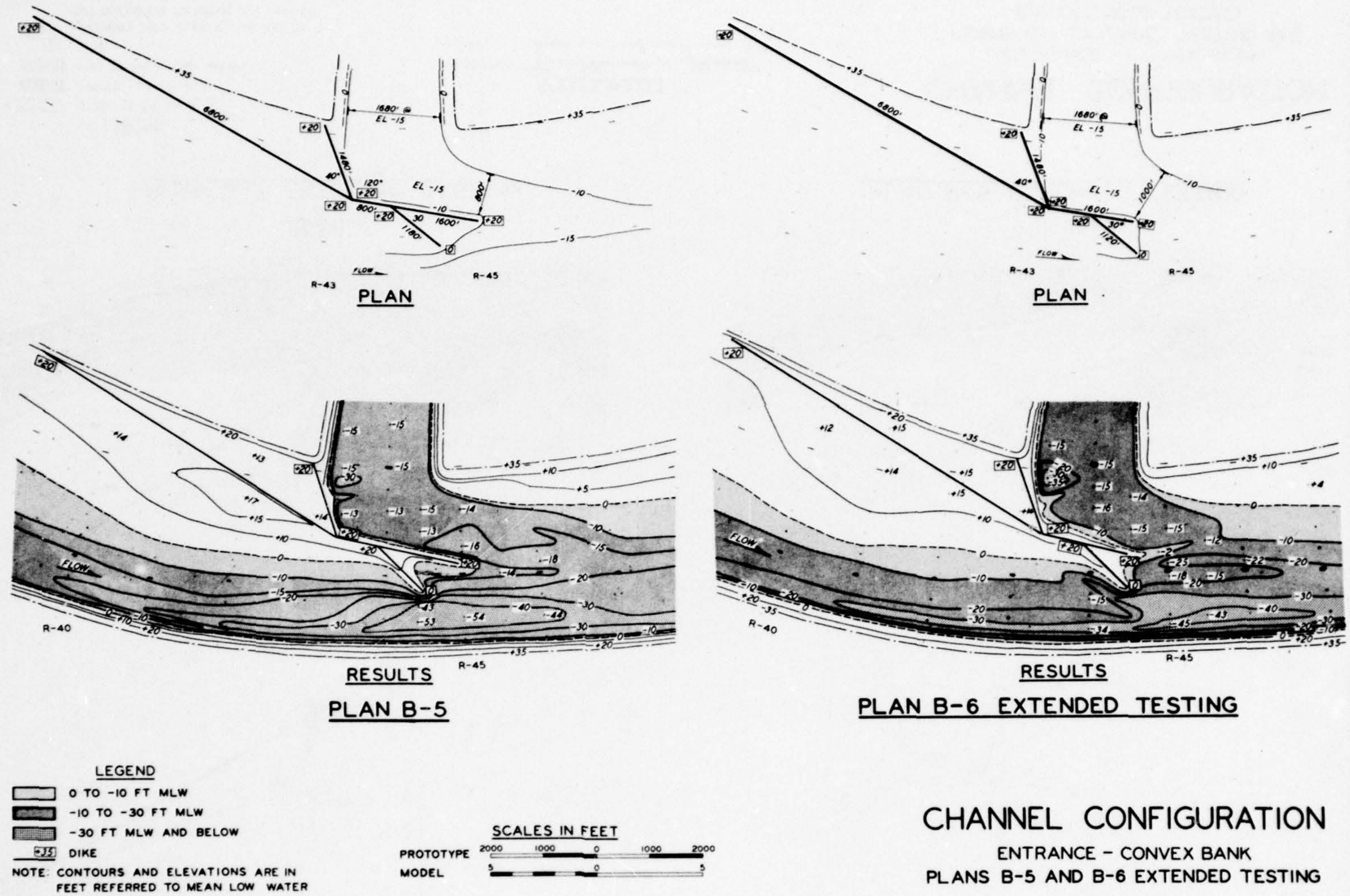
PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK
PLANS B-3 AND B-4

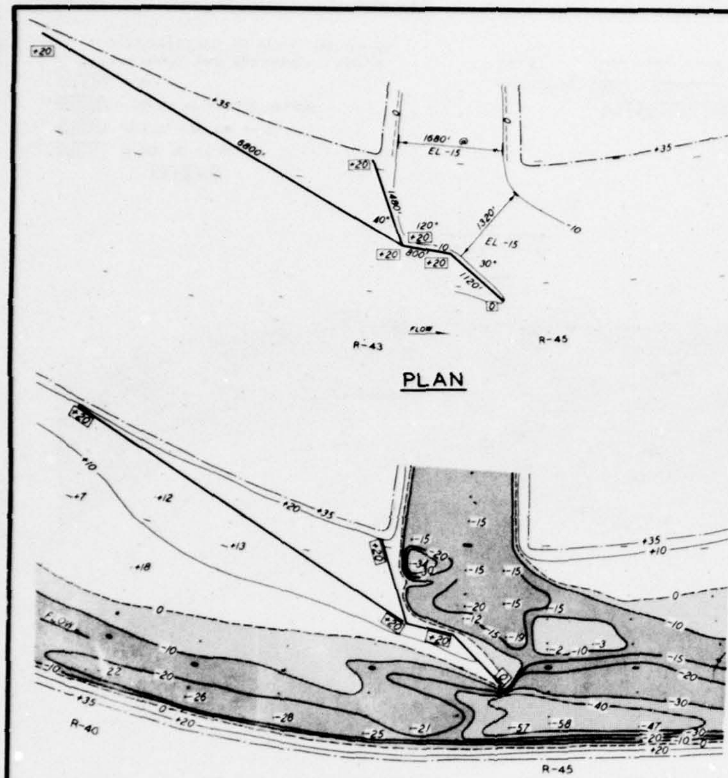
PLATE 22



CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK

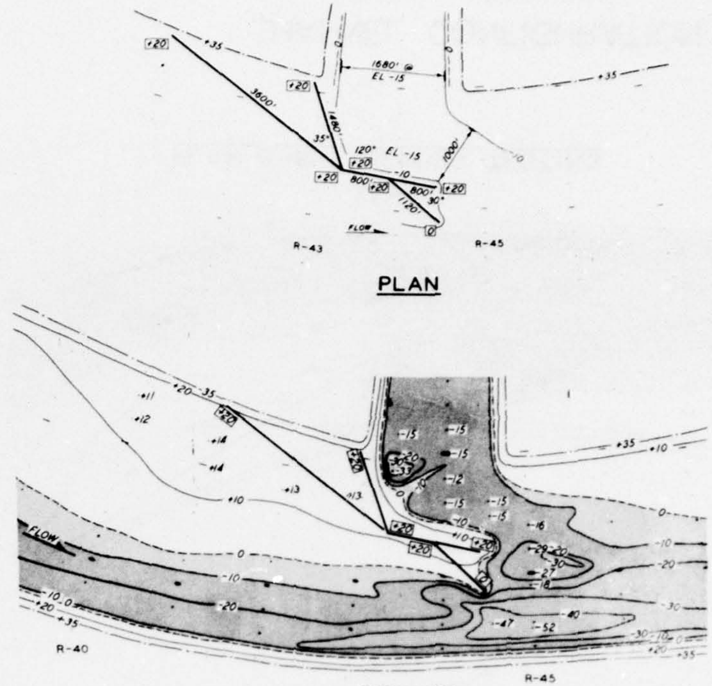
PLANS B-5 AND B-6 EXTENDED TESTING



PLAN

RESULTS

PLAN B-7 EXTENDED TESTING



PLAN

RESULTS

PLAN B-8 EXTENDED TESTING

LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

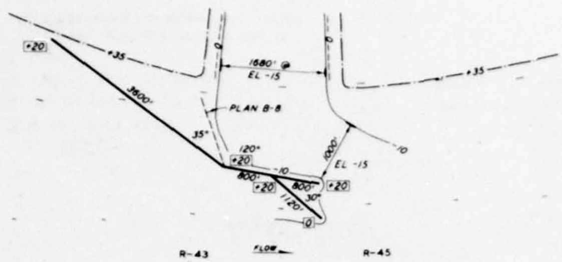
SCALES IN FEET

PROTOTYPE 2000 1000 0 1000 2000

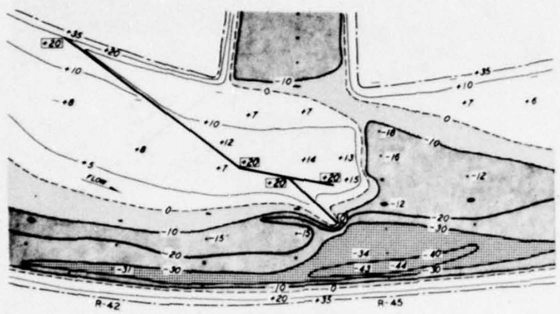
MODEL 5 0 5

CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK
PLANS B-7 EXTENDED TESTING AND
B-8 EXTENDED TESTING

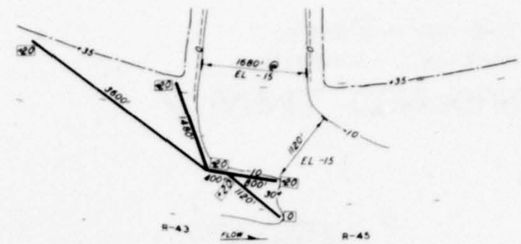


PLAN

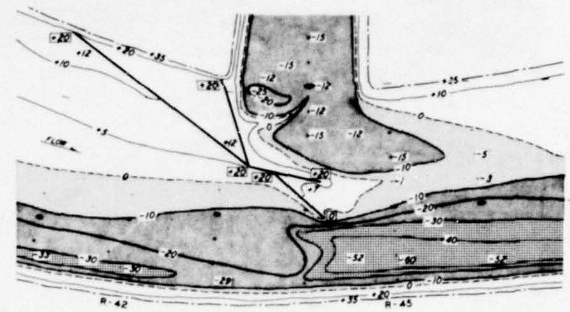


RESULTS

PLAN B-9



PLAN



RESULTS

PLAN B-10

LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

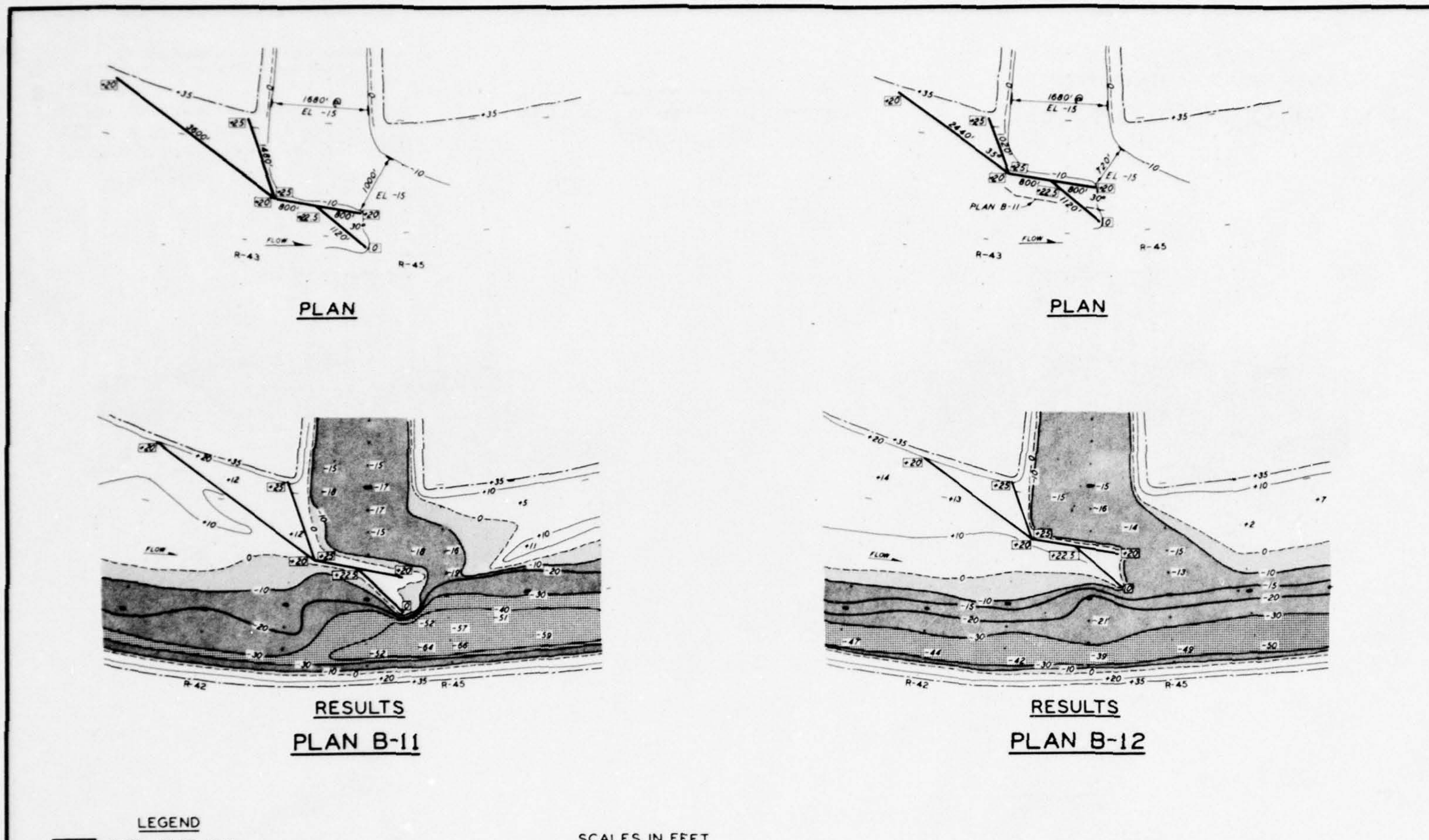
PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK

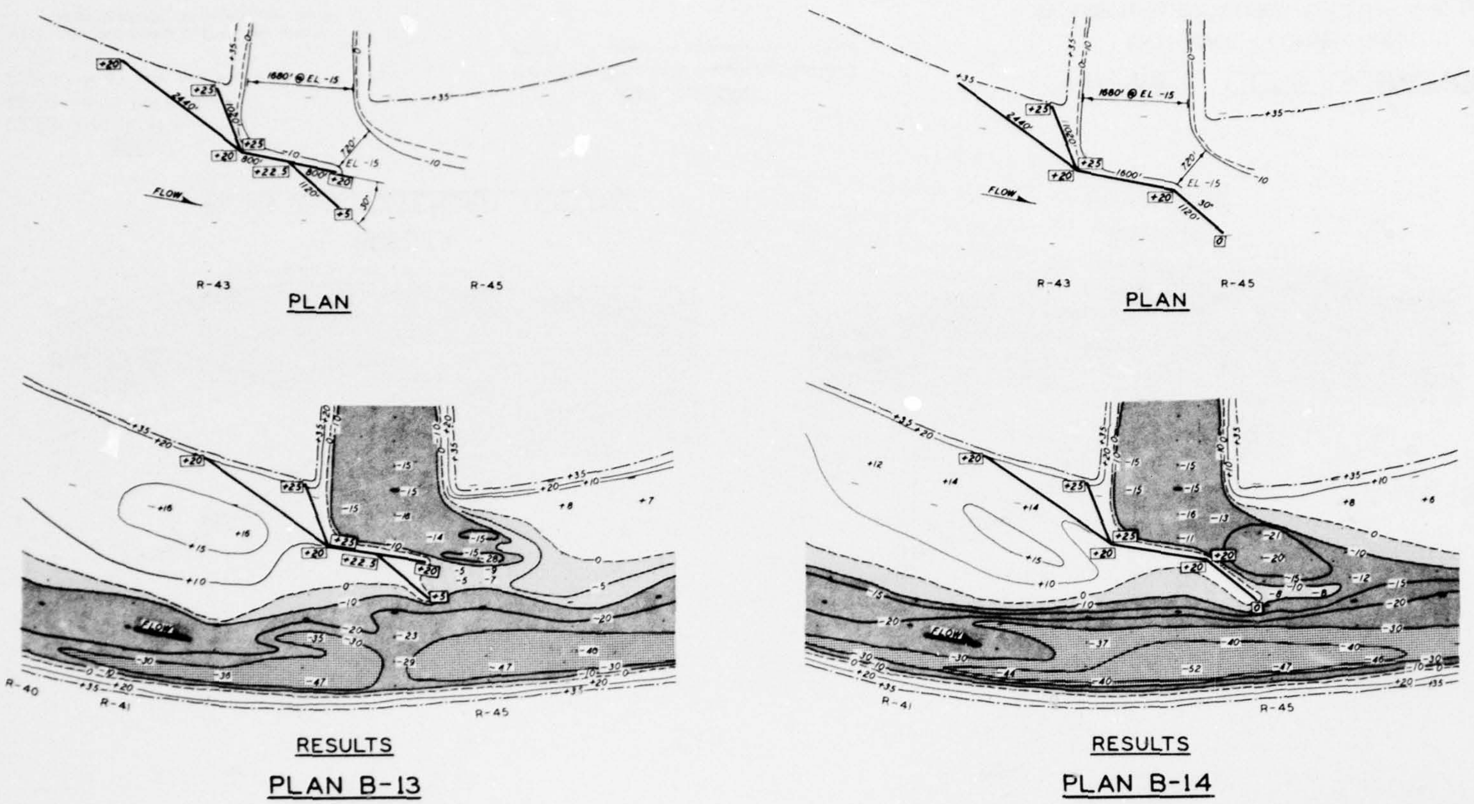
PLANS B-9 AND B-10



CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK

PLANS B-11 AND B-12



LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

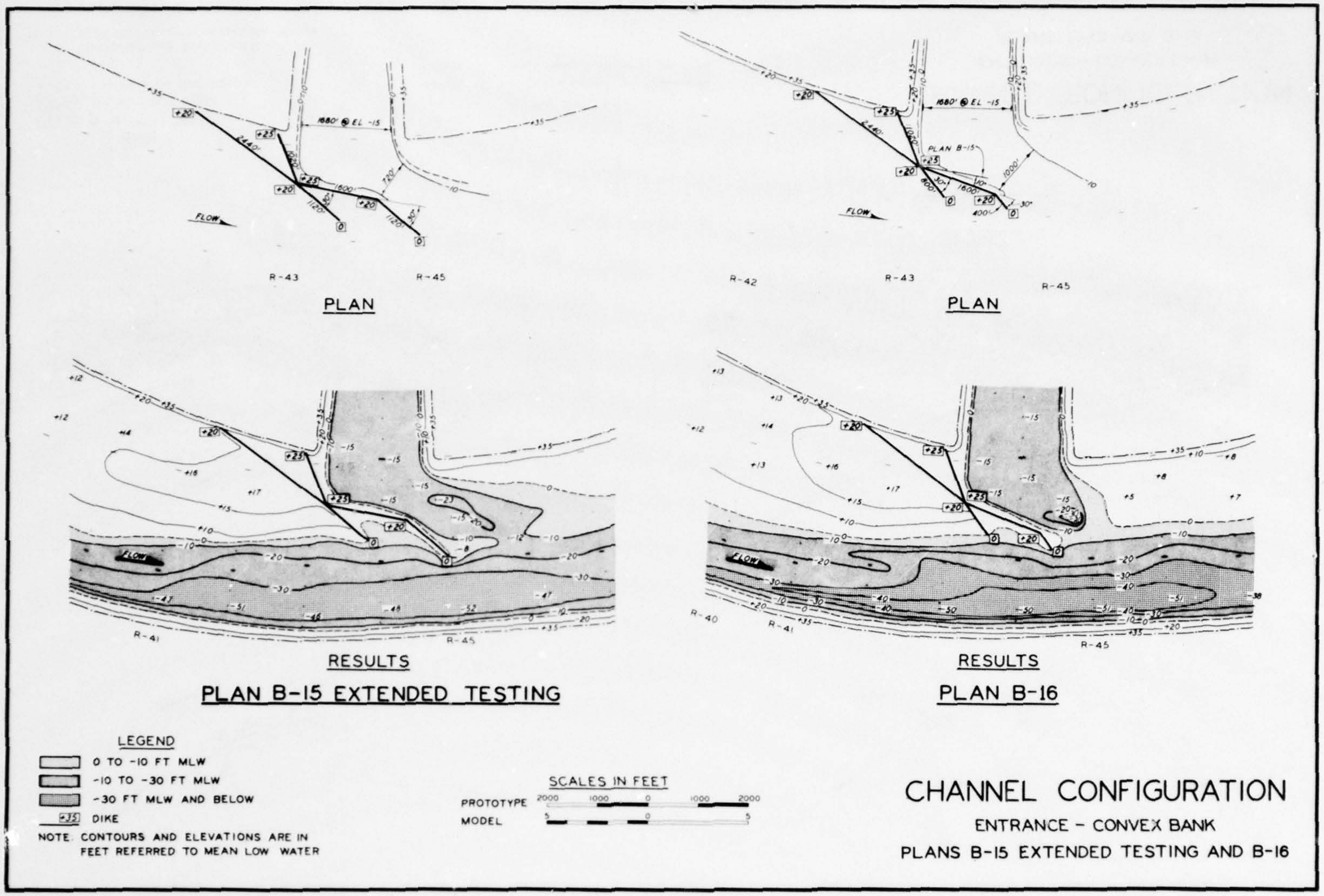
PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

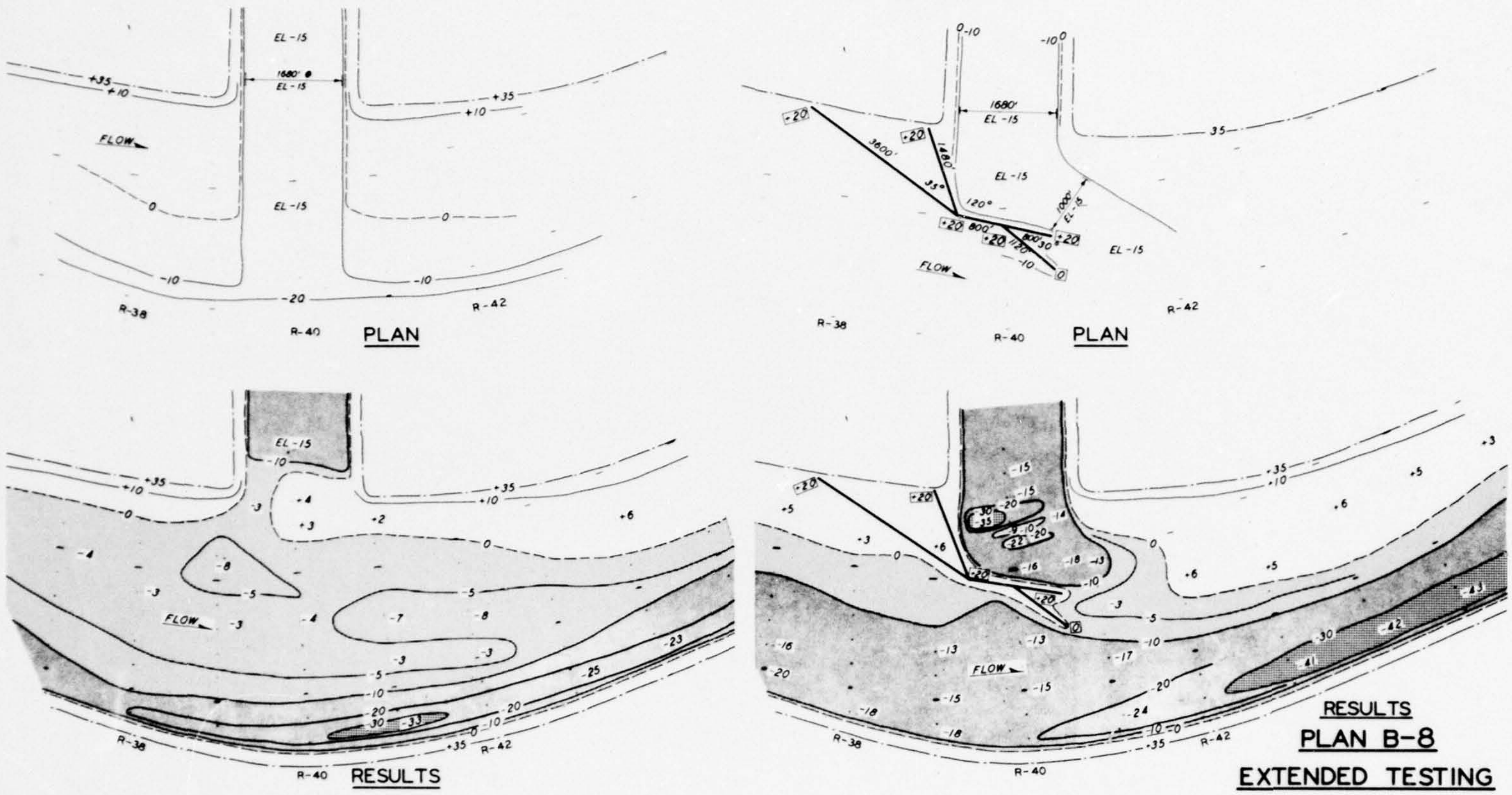
CHANNEL CONFIGURATION

ENTRANCE - CONVEX BANK

PLANS B-13 AND B-14



PLAN
PLAN B-15
1680' @ EL -15
FLOW
R-42
R-43
R-45
RESULTS
PLAN B-15 EXTENDED TESTING
RESULTS
PLAN B-16
LEGEND
0 TO -10 FT MLW
-10 TO -30 FT MLW
-30 FT MLW AND BELOW
+35 DIKE
NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER
SCALES IN FEET
PROTOTYPE 2000 1000 0 1000 2000
MODEL 5 0 5
CHANNEL CONFIGURATION
ENTRANCE - CONVEX BANK
PLANS B-15 EXTENDED TESTING AND B-16



LEGEND

- 0 TO -10 FT MLW
- -10 TO -30 FT MLW
- -30 FT MLW AND BELOW
- +35 DIKE

NOTE: CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN LOW WATER

SCALES IN FEET

PROTOTYPE 2000 1000 0 1000 2000

MODEL 5 0 5

CHANNEL CONFIGURATION

REVISED CHANNEL ALIGNMENT
ENTRANCE - CONVEX BANK
BASE, AND PLAN B-8 EXTENDED TESTING

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Melton, Bertrand K

Shoaling in harbor entrances; hydraulic model investigation / by Bertrand K. Melton, John J. Franco. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

37 p., 29 leaves of plates : ill. ; 27 cm. (Technical report - *U. S. Army Engineer Waterways Experiment Station* ; HL-79-5)

Prepared for U. S. Army Engineer Division, Lower Mississippi Valley, Vicksburg, Mississippi.

1. Harbor entrances. 2. Hydraulic models. 3. Movable-bed models. 4. Shoaling. I. Franco, John J., joint author. II. United States. Army. Corps of Engineers. Lower Mississippi Valley Division. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-79-5.

TA7.W34 no.HL-79-5